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TOTAL WORK, INTENSITY AND DURATION OF A TRAINING PROGRAM AS DETERMINANTS OF ENDURANCE FITNESS

by

© HOWARD ALLAN WENGER

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF PHYSICAL EDUCATION

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Total Work, Intensity and Duration of a Training Program as Determinants of Endurance Fitness" submitted by Howard Allan Wenger in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

ABSTRACT

The purpose of this study was to determine whether intensity or duration of training sessions is the primary determinant of endurance fitness if the total work accomplished by and the initial fitness levels within each group were equated.

Thirty six subjects (mean age 27.9 years) were ranked according to $M\dot{V}O_2$ in ml per kg per minute and then blocked into four fitness levels. The subjects from each fitness level were then randomly assigned to one of three groups. The first group (T100) trained at 100% of the work load which produced $M\dot{V}O_2$; the second group (T60) trained at 60% of the work load which produced $M\dot{V}O_2$ and the third group acted as a control. The training was accomplished on a bicycle ergometer and the program consisted of three sessions per week for seven weeks. The total work in both training groups was equated by having subjects of similar initial fitness in the different training groups perform the same work output.

After training, significant decreases in heart rate and blood lactate concentrations occurred for both training groups over the control at the work load which produced $M\dot{V}O_2$ on the initial test. There was no differences at this work load, however, between the two training groups.

Significant increases in maximum work load, maximum pulmonary ventilation, maximum oxygen consumption and oxygen pulse for both training groups over the control were found after training. The T100 group had

significantly higher work loads and $M\dot{V}O_2$ relative to body weight than did the T60 group after the training regimen.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

INTRODUCTION

Physical conditioning and its effect on cardio-respiratory fitness has long been of interest to physical educators, coaches, cardiologists and researchers. Cardio-respiratory fitness or, endurance fitness, is intimately related to the oxygen transfer process in the pulmonary system as well as at the cellular level of the working tissue. Because it is an indirect measure of the limit to which this oxygen transfer process can be taxed, the maximal oxygen consumption can be termed a good single measure of endurance fitness. Although endurance fitness is mainly involved with the aerobic energy-liberating processes, this type of fitness also implies an increased ability to utilize the anaerobic energy reserves and consequently infers an increased ability to tolerate anaerobic metabolites.

Many studies (17,19,23,24,34,63) have shown general exercise programs of running, jogging, walking and sports participation will increase the maximum oxygen consumption, the blood lactate tolerance at maximal work loads, and the work capacity. A principal point of contention, however, has been the quality and quantity of work necessary to bring about an optimal improvement in endurance fitness. In order to quantify the training stimulus a number of studies (60,68,69,73) have been carried out with intensity,

frequency and/or duration of the training program as the independent variables with various cardio-respiratory parameters as the dependent variable. In some cases (69,73) where intensity of effort was shown to provide the greatest improvement in endurance fitness, the increased intensity contributed to a greater total amount of work performed. This increased total work could have accounted for the improvements in endurance fitness. In a study (68) where total work was equated no significant differences between the groups was found. The failure to equate groups on initial fitness levels or giving the same absolute work load to all fitness levels could have led to the non-significant results. Roskamm(60) equated groups in total work and initial abilities and found that high intensity, interval type training was better than continuous, low intensity work. Although the interval versus continuous format tends to confound the comparison of high and low intensity groups, the importance of intensity as a training stimulus was illustrated.

THE PROBLEM

To determine whether intensity, total work or duration of a training program is the major contributor to cardio-respiratory endurance.

JUSTIFICATION OF THE STUDY

In trying to distinguish the primary training stimulus for cardio-respiratory fitness, it was necessary to equate groups on the following:

(a) initial fitness levels;

(b) total work performed;

(c) frequency of the training sessions; and then to vary the intensity of the training between the groups. To have given all the subjects within a training group the same absolute total work regardless of their initial fitness would have required the subjects to work at different relative work loads in terms of their maximum capacities. Since the training effect is directly related to the relative rather than the absolute work load (63), it was desirable to train all subjects within a training group at the same relative work load and still keep the work performed between the groups equated.

One group worked at 100% of their measured aerobic capacity for as long as the work could be maintained and the second group worked at 60% of their measured aerobic capacity for as long as it took to perform the same work output as the first group.

If the first group (100% maximum) improved more than the second group, intensity could be proposed as the training stimulus. If the second group (60% maximum) showed more improvement, duration of the training sessions could be proposed as the training stimulus. If there was no difference between the two groups but rather the same improvement in both groups, it could be argued that total work had elicited the training effects.

The group which trained at 100% of maximal aerobic capacity was taxing both the aerobic and anaerobic energy liberating processes while the group which trained at 60% of their aerobic capacity taxed, almost solely, the anaerobic processes. Thus some light could be shed on the question of

whether training one energy system can also improve the efficiency of the other process.

DELIMITATIONS OF THE STUDY

The study involved thirty-six members of the Edmonton Fire Department who volunteered to take part.

LIMITATIONS OF THE STUDY

Although the subjects were asked to maintain the same activity patterns as they had before the study, the experimenter could not control the activities outside of the laboratory training sessions.

DEFINITIONS OF TERMS

Aerobic Work: A given amount of work for which the oxygen supply is sufficient and hence anaerobic metabolism is not required to augment the aerobic energy processes.

Anaerobic Work: The accomplishment of a given amount of work for which the oxygen supply is not sufficient and hence other metabolic sources of energy must be utilized.

Blood Lactate: The lactic acid which is in the blood in the combined state with the blood buffers. Lactic acid is the end product of anaerobic metabolism of carbohydrate and is used as a measure of the extent to which the anaerobic energy supply mechanism has been engaged.

Initial Maximum Work Load: The work load at which a subject reached maximum oxygen consumption on the pre-training test.

Maximum Oxygen Consumption: The maximum volume of oxygen which the body can remove from the air per minute. It is used as a measure of the peak capacity of the cardio-respiratory systems to take up, transport, and release oxygen to the working tissues, and for these tissues to utilize the oxygen in energy production.

Oxygen Pulse: The amount of oxygen consumed per heart beat. This is used as a measure of cardio-respiratory efficiency.

Pulmonary Ventilation: The volume of air expired per minute and measured in litres at standard temperature and pressure, dry (STPD).

Ventilatory Equivalent: The pulmonary ventilation per litre of oxygen consumed per minute. This index is used as a measure of pulmonary efficiency.

CHAPTER II

REVIEW OF THE LITERATURE

THE EFFECT OF TRAINING ON MAXIMAL OXYGEN CONSUMPTION

Cureton and Phillips (17) trained six sedentary, middle-aged subjects for one hour per day, six days per week for eight weeks. The training program consisted of fifteen minutes of calisthenics, thirty to fifty minutes of cross country running and then thirty minutes of handball or squash. Maximum oxygen uptake was measured directly on the treadmill before, during and after the eight week program. A 35% improvement in $M\dot{V}O_2$ (ml per kg per minute) occurred over the eight weeks. The subjects were given an eight week rest during which $M\dot{V}O_2$ levels returned to approximately pre training values. A further eight week conditioning program consisting of the same items as the first regime but with the intensity increased was then given. Following this eight week program the $M\dot{V}O_2$ (ml per kg per minute) was again measured with the subjects showing about 93% (26.5 to 50.2 ml per kg per minute) improvement over pre training values. Significant weight loss over the program occurred which could have accounted for a portion of these large increases but exact figures were not given so the precise contribution of the weight loss to the improved $M\dot{V}O_2$ cannot be determined.

Ekblom et.al. (24) trained ten healthy male subjects (aged 19-27) in a cross country endurance running program interspersed with interval sprints. The program was followed for forty five to seventy five minutes

per day, three days per week for sixteen weeks. During the distance running the heart rates varied between 130 and 170 beats per minute and during the sprints, the rates fluctuated between 150 and 170 beats per minute. No record was kept of the proportion of time spent on each type of training. Maximum oxygen consumption was measured on a bicycle ergometer both before and after the training program. A significant improvement in $M\dot{V}O_2$ of 16.2% (3.15 to 3.68 litres per minute) over the training program was reported. This improvement was attributed to increased maximal cardiac output and increased arterio-venous oxygen difference, although the improvement in the latter parameter was not statistically significant.

Ekblom (22) separated fourteen boys (aged 11) into two groups - one control, one training. The training program lasted for six months with sessions of forty five to sixty minutes per day, twice a week. The program itself consisted of interval running, distance running, weight training, and ball games. Maximum oxygen consumption was measured before and after the training program on a bicycle ergometer. $M\dot{V}O_2$ showed a 15% increase in the trained group and no change in the controls.

Hartley et.al. (34) trained fifteen healthy male subjects (aged 38-55) for thirty minutes per day, two to three days per week, for eight to ten weeks in a program which involved only distance running. Maximum oxygen consumption was measured both prior to and following the training program and was shown to improve 14% (2.68 to 3.06 litres per minute) over the duration of the training. An increase in maximal cardiac output of 13% was proposed to account for the improved $M\dot{V}O_2$ since A-VO_2 difference did not change. As might be expected, the increase in cardiac output at maximal

loads was due to increased stroke volume (16%) as heart rates at maximum showed no significant change due to the training.

Naughton and Balke (54) trained six sedentary individuals five days per week for sixteen weeks with program consisting of running. Maximum oxygen consumption was measured on a treadmill before and after the program. The $M\dot{V}O_2$ (ml per kg per minute) increased over the training period by 43.3% (31.6 to 45.3 ml per kg per minute) even though body weight decreased by only 2.6% (79.5 kg to 77.4 kg).

Naughton and Nagle (55) trained eighteen men (mean age 41 years) for thirty minutes per day, three days per week, for seven months. The training involved a warm-up, conventional calisthenics, and intermittent running with intensity gradually increased throughout the program. Maximum oxygen consumption was measured prior to and following the program and showed a statistically significant increase of 15.3% (31.3 to 36.1 ml per kg per minute).

Pollock, Cureton and Greninger (57) divided twenty seven volunteer subjects (aged 28-39) into two training groups and a control group. Group 1 trained twice per week while Group 2 trained four times per week for twenty weeks, while the control group did not exercise. Exercise sessions were thirty minutes in duration and consisted of continuous walking, running or jogging. Maximum oxygen consumption was measured on the treadmill prior to, middle of, and at the end of the twenty weeks. After ten weeks of training, the $M\dot{V}O_2$ for Group 1 showed an increase of 13.5% (36.7 to 42.8 ml per kg per minute) and over the twenty weeks improved 17% (37.7 to 44 ml per kg per minute) after ten weeks and 35% (36.7 to 49.3 ml per kg per minute) over

the twenty week program.

Ribisl (58) trained fifteen sedentary middle aged men (aged 40.2 years) for thirty five minutes per day, three days per week, for five months. The training sessions consisted of calisthenics, interval running, and cross-country running. The caloric cost of the training sessions was approximately 300kcal per hour in the first month and about 750kcal per hour in the final month. Maximum oxygen consumption was measured on a treadmill prior to and following the training period and showed a 14% improvement (40.1 to 45.5 ml per kg per minute) over the five months.

Saltin et.al. (63) in a very thorough longitudinal study on the effects of bed rest and training, selected six male subjects (aged 19-21) and tested them in a control state, then following twenty days of bed rest, and again after fifty three to fifty five days of training. The study included a complete analysis of circulatory, respiratory, blood and anthropometric parameters. The training was carried out for about one hour per day, six days per week, for eight weeks and consisted of both interval and continuous running. The oxygen uptake during the interval running was at or near maximal while the oxygen uptake of the continuous work was from 65-90% of the persons maximal capacity. The maximum oxygen uptake increased by 33% over the control values due to the training program (2.52 to 3.41 litres per minute) which could be attributed to increased stroke volume (17%) and increased arterio-venous oxygen difference (5.6%).

Saltin, Kilbom and Åstrand (65) trained forty two subjects (mean age 40.5 years) approximately twenty five minutes per day, two to three days per week, for eight to ten weeks with a program that consisted

of walking, jogging, strength exercises and a two mile run. Twice per week the running was of an intermittent nature while the third session involved continuous activity. The interval running taxed the aerobic system almost maximally (98-99%) while the continuous work was accomplished at 91-97% of the subjects maximal capacity. The maximum oxygen consumption was measured on a bicycle ergometer and showed a 19% improvement (2.89 litres to 3.44 litres per minute) over the training period.

Sharkey (68) attempted to control total work done in a training program and to vary the intensity and duration of the exercise. Thirty six subjects (mean age 19.5 years) were assigned to either 7500 kpm or 15,000 kpm of total work for each training session and intensity levels were based on heart rates of 130, 150, or 170 beats per minute. The subjects trained three times per week for six weeks on a bicycle ergometer. No significant differences between the groups or the treatments and no interaction effects were reported. A control group was not used nor were the groups equated according to initial capacities. Within each total work group (i.e. 7500 kpm or 15,000 kpm) there was a wide range of initial fitness levels and since the work loads were in absolute rather than relative physical units, a greater training stress would be put on those of lower fitness levels and could account for the non-significant differences.

Sharkey and Holleman (69) divided sixteen subjects (aged 18-19) into three training groups and a control group. The training groups exercised at heart rates of either 120, 150 or 180 beats per minute for ten minutes per day, three days per week over six weeks. Maximum oxygen consumption was estimated by the Åstrand-Rhyming nomogram. Significant improvements in the 180 heart beat per minute training group only were found. No attempt was

made to equate groups on total work done or initial abilities.

Shephard (73) trained twenty five men at one of three intensities (35%, 65% and 90% of their aerobic capacity) for one of three durations (5, 10 or 20 minutes per day) for one of three frequencies (1, 3 or 5 times per week) and found that after six to ten training sessions an improvement of 5.0% (35.6 to 37.4 ml per kg per minute) in the lowest intensity group and 12% (35.6 to 40 ml per kg per minute) in the high intensity group. It was reported that the best combination involves maximum intensity, frequency and duration of effort.

Seigel, Blomquist and Mitchell (67) trained nine blind subjects (aged 32-59) twelve minutes per day, three times per week for fifteen weeks on the bicycle ergometer. The training regimen consisted of three rides of four minutes duration with a four minute rest between each. Heart rates during the last minute of each ride averaged twenty seven beats below maximum values. Maximum oxygen uptake was measured directly and showed a 19% (24.0 to 28.5 ml per kg per minute) increase over the fifteen weeks.

THE EFFECT OF TRAINING ON PULMONARY VENTILATION

Davies, Tuxworth and Young (19) trained five healthy, male subjects (aged 17-23) for sixteen days. The subjects performed maximal and submaximal tests on alternate days and changes in maximum pulmonary ventilation were recorded over the sixteen day period. No significant change in maximum pulmonary ventilation was found.

Durnin, Brockway and Whitcher (21) trained forty five voluntary subjects (aged 18-22) from the Royal Air Force for a period of about two weeks. The men were divided into four groups, three experimental and one control. The three training groups walked either 10, 20 or 30 kilometers

per day, five days per week for two weeks. Pulmonary ventilation was measured prior to, during and after the ten days of training. The test itself was performed on a treadmill and was of a submaximal nature i.e. walking on the treadmill at 5.6 km per hour for fifteen minutes at a 10% grade. Only the 20km per day training group showed a significant decrease in pulmonary ventilation (61.0 to 55.3 litres per minute BTPS).

Ekblom (24) trained eight male subjects for sixteen weeks (see page 8). The sixteen week training program of cross-country and interval running produced a decrease in pulmonary ventilation (113.4 to 93.3 litres per minute at BTPS) at the initial maximum load and an increase in maximum pulmonary ventilation (113.4 to 127.5 litres per minute at BTPS) occurred as a result of the training program.

Ekblom (22) trained fourteen subjects (aged 11) for six months (see page 8). A significant decrease (39.3 to 36.0 litres per minute at STPD) in pulmonary ventilation occured at submaximal work loads. Maximum pulmonary ventilation, however, increased significantly (68.0 to 80.4 litres per minute at STPD) over the six months.

Hartley et.al. (34) trained fifteen healthy male subjects (aged 38-55) for eight to ten weeks (see page 8). A decrease in pulmonary ventilation (64.1 to 61.7 litres per minute at BTPS) at a submaximal work loads as a result of the training program were reported.

Hermansen and Anderson (35) in a horizontal study, analyzed many fitness parameters of population, fourteen top athletes and twelve students. The pulmonary ventilation at maximum was 118$\pm$ 5 litres per minute and 83$\pm$4 litres per minute (BTPS) respectively.

Naughton and Nagle (55) trained eighteen men (mean age 41) for seven months (see page 9). Their training program resulted in a decrease in pulmonary ventilation (69 to 64 litres per minute BTPS) on a submaximal treadmill test.

Pollock, Cureton and Greninger (57) trained nineteen volunteer men (mean age 32.5) for twenty weeks (see page 10). In the group that trained two days per week the maximum pulmonary ventilation increased (127.2 to 137.9 litres per minute BTPS) after ten weeks and showed a further increase (173.9 to 140.8 litres per minute BTPS) after twenty weeks. The group which trained four times per week showed an increase in maximum pulmonary ventilation (128.9 to 140.2 litres per minute BTPS) after ten weeks and a further increase of (140.2 to 142.6 litres per minute BTPS) after the twenty week program.

Ribisl (58) trained fifteen middle aged men (mean age 40.2) for five months (see page 10). A significant increase in maximal pulmonary ventilation (129 to 143 litres per minute) after the five month training program was found.

Saltin et.al. (63) (see page 10) showed an increase in pulmonary ventilation (129 to 156 litres per minute BTPS) at maximal work with a training program of eight weeks. The increase was attributed to an increase in respiratory rate as the tidal volume was not changed.

Saltin et.al. (65) also showed (see page 11) an increase in maximal pulmonary ventilation of 15% (112.1 to 128.0 litres per minute BTPS) over a training program of eight to ten weeks using forty two subjects (aged 35-50) However, no significant decrease at submaximal work loads over the training

period was reported.

THE EFFECT OF TRAINING ON HEART RATE

Brouha (8) reported a study using twenty one subjects from a rowing team. Heart rate at maximal loads prior to and following a training program was measured and showed a 7.3% decrease (191 to 177 beats per minute) at the previous maximum load.

Davies, Tuxworth and Young (19) (see page 13) showed a significant decrease in heart rate (145 to 124 beats per minute) after seven days of a training program which involved submaximal and maximal work on an alternating day basis. The study failed to show any decrease in maximal heart rate over the sixteen day program but a decrease was found (196 to 189 beats per minute) at the point where oxygen consumption levelled off.

Durnin, Brockway and Whitcher (21) in their short training program of two weeks (see page 13) and using a submaximal test, found a significant decrease in heart rate at submaximal loads in both the twenty km per day and thirty km per day training groups.

Ekblom (22) in a training study with 11 year old boys (see page 8) found a significant decrease (147 to 139 beats per minute) in heart rate at a given submaximal load after six months of training but did not show a significant decrease at maximal work.

Ekblom et.al. (24) using eight male subjects (aged 19-27) and training them for sixteen weeks (see page 8) tested subjects with catheters for blood volume and pressure readings. A significant decrease in heart rate (13 beats per minute) at submaximal loads requiring one and two litres

of oxygen uptake was reported. At the previous maximum, the heart rate decreased from 200 to 179 beats per minute as a result of training. A significant decrease in maximal heart rates (200 to 192 beats per minute) over the sixteen weeks was observed. In a test without the catheters, the study failed to obtain the significant reduction at maximal work.

Frick, Konttinen and Sarajas (29) tested fourteen men (aged 19-26) prior to and following hard basic training in the Finnish military for two months. No significant decrease at a submaximal work load (400 kgm per minute) was reported.

Hartley et.al. (34) trained fifteen sedentary men (aged 38-55) for eight to ten weeks (see page 8) and reported a significant decrease in heart rate (161 to 144 beats per minite) at a submaximal work load (900 kpm per minute) as a result of the training program. A significant decrease in maximal heart rate (182 to 176 beats per minute) over the training period also occured.

Knehr, Dill and Neufeld (43) trained fourteen subjects with middle distance running, three times per week, for six months. Bi-weekly submaximal and maximal tests on a treadmill were also performed. A decrease of 3.3% (151 to 146 beats per minute) in heart rates at a submaximal work load and no change in heart rates at maximal work was found.

Naughton and Nagle (55) trained eighteen men (mean age 41) for seven months and tested them prior to and following the program (see page 9). This study revealed the heart rates at submaximal workloads on the treadmill (e.g. 12% grade, 3.4 m.p.h.) decreased significantly over the training period (167 to 156 beats per minute).

Pollock, Cureton and Greninger (57) trained nineteen sedentary men (mean age 32.5) for either two times per week or four times per week for twenty weeks (see page 10). The maximal heart rate decreased significantly over the first ten weeks (from 187.8 to 180.2 beats per minute) for the four times per week group and decreased significantly over the twenty week period (from 186.2 to 181.9 beats per minute) for the twice per week training group.

Ribisl (58) found, that after training fifteen subjects (mean age 40.2) for five months with a running program (see page 10), the maximum heart rate did not decrease significantly.

Saltin et.al. (63) in a longitudinal study over fifty five days of training (see page 10) found a significant decrease in heart rate (129 to 115 beats per minute) at a submaximal work load requiring 1.5 litres of oxygen per minute. The maximal heart rates, however, showed no significant change over this time (193 to 191 beats per minute).

Saltin et.al. (65) after training forty two subjects (aged 34-50) for eight to ten weeks (see page 11) found a decrease in heart rate (155 to 138 beats per minute) at a submaximal work load of 900 kpm per minute. The maximal heart rate in these subjects also decreased over the training period (190 to 183 beats per minute).

Seigel, Blomquist and Mitchell (67) trained nine blind subjects (aged 32-59) for fifteen weeks (see page 13) and found no reduction in maximal heart rates over the training program (167 to 164 beats per minute).

THE EFFECT OF TRAINING ON BLOOD LACTATE CONCENTRATIONS

Brouha (8) reported that following a training program given to a

group of college oarsmen, the blood lactate levels at the initial maximum work load decreased significantly (105 to 80 mg%).

Cunningham and Faulkner (16) found after training eight males for six weeks, that the blood lactate at maximal work had increased by 17% (101 to 118 mg%). The training program consisted of interval sprints and distance running.

Ekblom (22) reported no significant decrease in blood lactate concentration occured (1.9 to 1.8 mM) at submaximal work (450 kpm per minute) after training (see page 8). It was also found that maximal blood lactate concentration was not effected by the six month training program (8.7 to 8.3 mM).

Ekblom et.al. (24) trained eight male students for sixteen weeks (see page 8) and stated that blood lactate concentrations at the initial maximum load decreased (12.9 to 9.5 mM) while the concentration at maximal loads increased slightly (12.9 to 13.6 mM) over the training period.

Knehr, Dill and Neufeld (43) measured maximal blood lactates prior to and following a training program of six months using fourteen subjects (see page 18). An increase of 14.9% in maximal lactate concentration (114 to 131 mg%) occured over the six month period.

Robinson and Harmon (59) trained nine non-athletic college students (aged 18-22) four days per week for six months. The training program consisted of supervised running on Tuesday, Wednesday and Thursday of each week and a time trial on Saturday. The actual running consisted of over distances combined with pace and speed work. The subjects were tested after each month of the program on a treadmill with both maximum and submaximum

tests. Blood samples were taken five minutes after the end of the running and lactate analyses performed. An increase in blood lactate (13 to 17.9 mM) at maximal work over the six months was shown and also a decrease in blood lactate concentration at the previous maximal work (13.7 to 9 mM) as a result of training was observed.

Saltin et.al. (65) found the training program (see page 11) of eight to ten weeks resulted in a decrease in blood lactate levels (6.3 to 4.7 mM) at a submaximal work load and an increase (12.8 to 14.0 mM) at maximal levels. The blood samples were taken during the first minute of recovery and a value of 7 mM of blood lactate was a minimum for the exercise to be termed maximal.

THE EFFECT OF TRAINING ON THE OXYGEN PULSE

Hermansen and Andersen(35) in a horizontal study designed to compare athletes and non-athletes, utilized the ratio of oxygen consumption to the heart rate to give a measure of the amount of oxygen consumed per heart beat. Much higher values for athletes than for the sedentary subjects (27.2 versus 17.0) at maximal work were reported.

Pollock, Cureton and Greninger (57) found a significant increase in the maximum oxygen pulse over ten weeks in a group that trained (see page 10) four times per week (16.6 to 19.81 ml per beat). In another group that trained twice per week for twenty weeks the maximum oxygen pulse also increased significantly as a result of the training (16.32 to 21.65 ml per beat).

Ribisl (58) confirmed the above results and, although the increases reported in his study over five months are not as large, they were significant

(19.0 to 21.2 ml per beat).

THE EFFECT OF TRAINING ON THE VENTILATORY EQUIVALENT

Saltin et.al. (63) failed to obtain any significant change in the ventilatory coefficient over fifty five days of training and reported that any increase in oxygen consumption at maximal loads was directly proportional to changes in pulmonary ventilation.

Saltin et.al. (65) confirmed the previous findings as regards ventilatory equivalent and reported that the increase in pulmonary ventilation was related to an increase in maximum oxygen consumption. Thus the ratio of pulmonary ventilation to oxygen consumption remained unchanged both at maximal work and submaximal work.

CHAPTER III

METHODS AND PROCEDURES

SAMPLE

Thirty six male volunteer subjects from the Edmonton Fire Department were used in this study. The age range of the subjects was twenty three to thirty six years with the mean age being 27.9 years.

TESTING SCHEDULE

The subjects came to the research laboratories in the Faculty of Physical Education at the University of Alberta to be tested during the three days prior to the start of the training program. They were then tested again at the same time of day during the three days following the seven week program.

PHYSICAL CONDITIONS IN THE LABORATORY

The temperature in the laboratory was maintained thermostatically at $22 \pm 2^{o}C$ but the humidity was not controlled.

CALIBRATION OF THE TEST GASES AND INSTRUMENTS

The test gases were checked with a Micro Scholander apparatus prior to both testing sessions according to the modified Scholander technique of Taylor (81). The Beckman E-2 oxygen analyzer and the Godart Capnograph were then calibrated with the test gases on the morning of

every testing day. The correction factor for converting the gas volume to STPD was taken three times per day during each testing day.

COLLECTION AND ANALYSIS OF GASES

A Collins triple J valve was connected to a lightweight aluminum headgear and fitted with a sterilized rubber mouthpiece for easy attachment to the subject. A lightweight, low-resistant, flexicoil, plastic hose was attached to the "out" vent on the J valve and coupled to a Douglas Bag. The subjects' noses were clamped with a rubber clip. Expired air was then collected, at the desired time, in the Douglas Bag. The collected air was analyzed for oxygen content with a Beckman E-2 oxygen analyzer and for carbon dioxide with a Godart Capnograph. The volume of expired air was measured in a Parkinson Cowan volume meter. An Olivetti 101 desk computer was pre-programmed with the formula from Consolazio, Johnson, and Pecora (13) so that an input consisting of the:

(a) volume of gas expired (BTPS) litres per minute;

(b) correction factor to STPD;

(c) body weight in pounds;

(d) Beckman E-2 oxygen analyzer reading;

(e) % concentration of carbon dioxide in expired air obtained from the Godart Capnograph.

gave an output of the following parameters:

(a) % oxygen in the expired air;

(b) volume of expired air (litres per minute STPD);

(c) volume of inspired air (litres per minute STPD);

(d) oxygen consumption (litres per minute STPD);

(e) oxygen consumption (ml per kg per minute).

BLOOD SAMPLING AND ANALYSIS

Blood samples were taken by a registered medical technician from the brachial vein. The protein was precipitated and then the serum analyzed for lactate concentrations via the enzyme method described in the Sigma Technical Bulletin (77).

TESTING PROCEDURE

Pre-Training Test

Subjects came to the laboratory and were weighed on a medical scale and given a one minute warm-up by pedalling a Monarch bicycle ergometer at zero load. Electrodes were attached and connected via patient leads to a Sanborn Electrocardiography preamplifier. The Collins triple J valve and head harness were attached to the subject and the nose clip put in place. A maximum oxygen consumption test was then performed according to the method of Åstrand (2) as modified by Macnab, Conger and Taylor (47). Heart rates were recorded during the fourth minute of work at each work load on a Sanborn ECG recorder. Blood samples were taken fifteen to thirty seconds following each work load.

Gas analyses were performed during the five minute rest interval and calculation of the oxygen consumption was accomplished during this recovery period by inputting the data from the gas analysis into the programmed Olivetti 101 computer.

Post-Training Test

The work loads during the post-training test included the maximum work load which was attained on the initial test and then further increases up to the new maximum load. Control subjects during the Post-training test, however, worked at the same loads in the initial test and only exceeded their previous maximum if their $M\dot{V}O_2$ had not plateaued.

ASSIGNING OF SUBJECTS TO THE TRAINING PROGRAMS

Following the pre-training test, all subjects were ranked according to their maximum oxygen consumption in ml per kg per minute. They were then divided into four blocks with nine subjects. The nine subjects from each block were then randomly assigned to either of three groups:

(a) training group (T100) to train at 100% of their pre-training maximum work load;

(b) training group (T60) to train at 60% of their pre-training maximum work load;

(c) control group (c) who were asked to maintain their same activity pattern for seven weeks.

Thus there were twelve subjects in each treatment group consisting of three subjects from each of the four blocks. The group means on $M\dot{V}O_2$ ml per kg per minute were therefore equated and were:

(a) T100 - 39.5 ml per kg per minute;

(b) T60 - 39.3 ml per kg per minute;

(c) C - 40.2 ml per kg per minute.

EQUATING THE WORK BETWEEN THE TWO TRAINING GROUPS

In order to equate the work between the two experimental groups and still allow individual subjects to work at 100% or 60% of their maximum capacities, subjects of similar initial fitness, but in different training groups, were yoked together. The T100 group was then asked to ride at their individual maximum loads (as measured on the initial test). The metronome was set for fifty revolutions per minute and the tension (kp) set so that the work load was maximum. Revolutions were counted mechanically which allowed the precise work output to be calculated (tension (kp) x revolutions x six meters). The subjects from T100 were told to ride for as long as possible on a continuous basis and attempt to keep pace with the metronome. When a subject stopped, his total work output was calculated. This total work was then assigned to a subject in T60 of similar initial fitness and similar body size. Before the subject in T60 performed the work output of his "partner", the experimenter took 60% of the tension which produced the maximal work for that subject, multiplied that value by six (meters) and divided this into the total work which had been performed by the "partner" in T100. This gave the number of revolutions which had to be completed by the subject in T60. In each training session and for the entire training program, the work output in kpm was the same for both experimental groups.

STATISTICAL PROCEDURES AND EXPERIMENTAL DESIGN

<u>The Design</u> (for diagrammatical display see Appendix D).

The experimental design utilized was a 3 x 4 x 2 factorial design (fixed model) with repeated measures on factor C (88).

The three levels of factor A (treatments) were:

(a) high intensity (100% $M\dot{V}O_2$) and short duration;

(b) lower intensity (60% $M\dot{V}O_2$) and long duration;

(c) control.

The four levels of factor B (initial fitness level) were the four blocks into which the subject had been assigned according to their initial scores on the $M\dot{V}O_2$ test.

The two levels of factor C were the:

(a) pre-training test scores;

(b) post-training test scores.

Statistical Analysis

The data on each parameter was analyzed initially by a three way analysis of variance with repeated measures as discussed by Winer (88). If significant F ratios were obtained, the data was plotted and a decision made on which simple main effects were to be tested. The numerator of the F ratio to test simple main effects was the mean square between groups from a normal one-way analysis of variance. The denominator, however, was a pooled error term obtained from the three way analysis done previously (see Winer 88). Where F ratios for simple main effects were significant, a Newman-Keuls test was used as a comparison between means (88). All computations were done via the IBM 360 computer at the University of Alberta.

CHAPTER IV

RESULTS AND DISCUSSION

RESULTS AT INITIAL MAXIMUM WORK LOAD

The pre and post training values on the various parameters are tabulated in Table 1 (mean $\pm$ S.D.).

Workload

The work loads at maximum on the pre-training test for the different training groups were 1350 $\pm$ 230.6 kpm per minute (T100), 1275 $\pm$ 163.1 kpm per minute (T60), and 1350 $\pm$ 263.7 kpm per minute (c).

Pulmonary Minute Ventilation ($\dot{V}_E$)

The $\dot{V}_E$ at the initial maximum load showed a significant decrease after the seven week training program. Although the T100 and T60 groups decreased 19.67 and 16.49 litres per minute respectively (see Figure I) this decrease was not significantly different from the control group. Neither the treatment (A) main effects nor the treatment x time (AC) interaction were significant (Appendix A-I,i) so an attempt to analyze the simple main effects was not justified.

Oxygen Consumption ($\dot{V}O_2$)

There was no significant change in the gross oxygen consumption at the initial maximum work load. Both groups T100 and C showed very slight

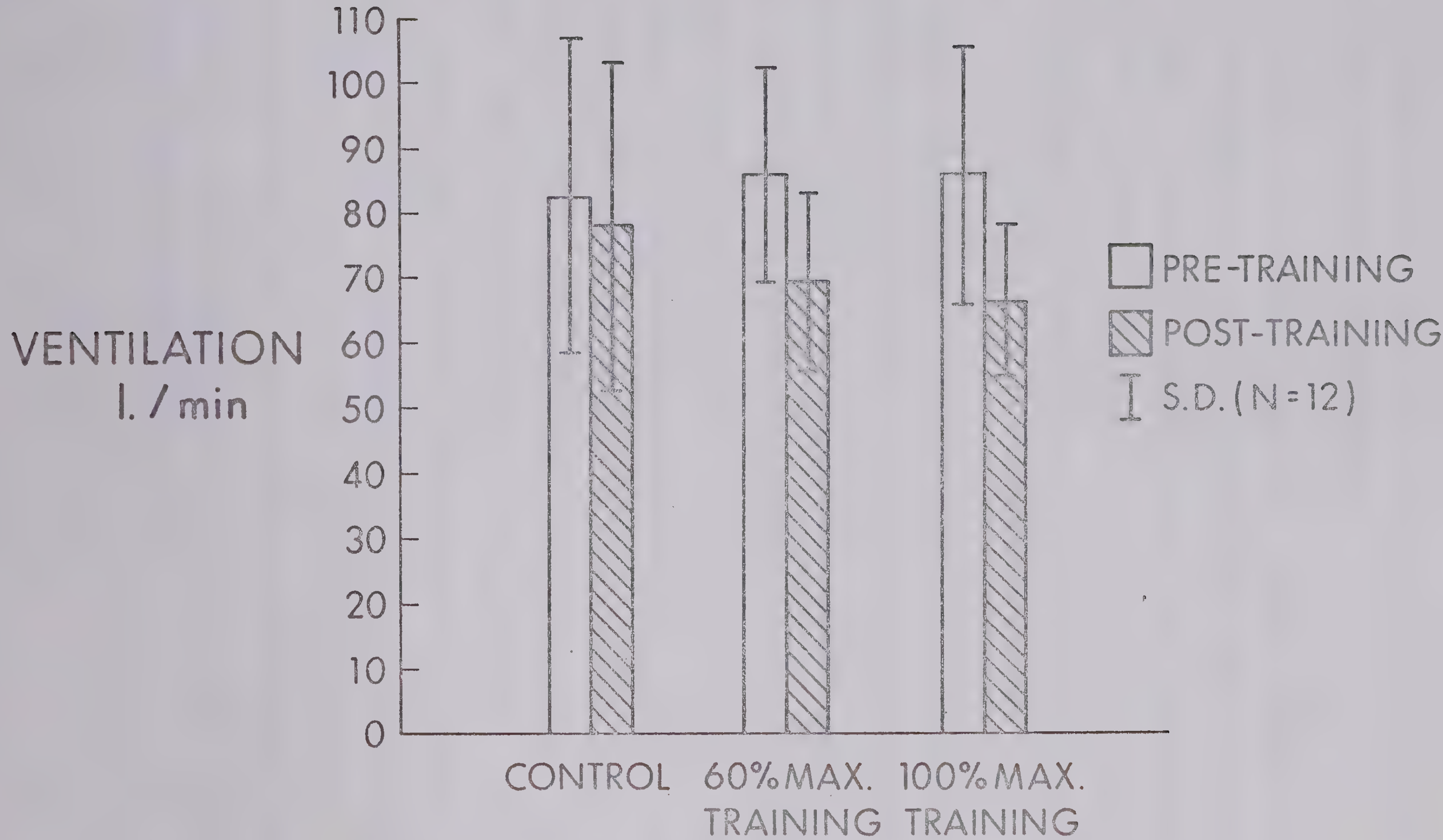
TABLE 1

GROUP MEANS FOR VARIOUS PARAMETERS AT INITIAL MAXIMUM WORK LOADS

AS OBTAINED AT PRE AND POST TRAINING TESTS

Training Program	Work Load Kpm/min.	$\dot{V}_E$ litres/min.		$\dot{V}O_2$ litres/min.		$\dot{V}O_2$ ml/kg/min.		HR Beats/min.		HLa mg%		V_E/VO_2		O_2pulse	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1(T100) Mean ± S.D. (n=12)	1350 (12) ± 230.6	83.6 ± 19.9	66.13 ± 11.56	3.03 ± 0.45	3.17 ± 0.57	39.50 ± 7.27	41.81 ± 9.99	185.7 ± 6.0	161.7 ± 10.0	84.92 ± 15.62	49.33 ± 14.35	27.2 ± 5.4	20.8 ± 1.9	16.35 ± 2.85	19.74 ± 2.76
2(T60) Mean ± S.D. (n=12)	1275 (12) ± 163.1	85.6 ± 16.4	69.15 ± 13.85	3.04 ± 0.56	3.04 ± 0.46	39.30 ± 7.56	39.95 ± 7.95	184.3 ± 7.9	163.0 ± 10.3	82.58 ± 21.13	55.33 ± 16.43	29.0 ± 7.6	22.8 ± 3.7	16.58 ± 3.51	18.72 ± 2.97
3(C) Mean ± S.D. (n=12)	1350 (12) ± 263.7	85.8 ± 24.2	77.87 ± 25.72	3.11 ± 0.80	3.22 ± 0.75	40.21 ± 10.02	41.69 ± 9.42	184.6 ± 7.7	182.6 ± 6.35	67.5 ± 21.16	69.08 ± 21.00	27.9 ± 6.7	24.3 ± 4.6	16.91 ± 4.40	17.71 ± 4.31

FIGURE I MINUTE VENTILATION AT INITIAL MAXIMUM WORK LOAD



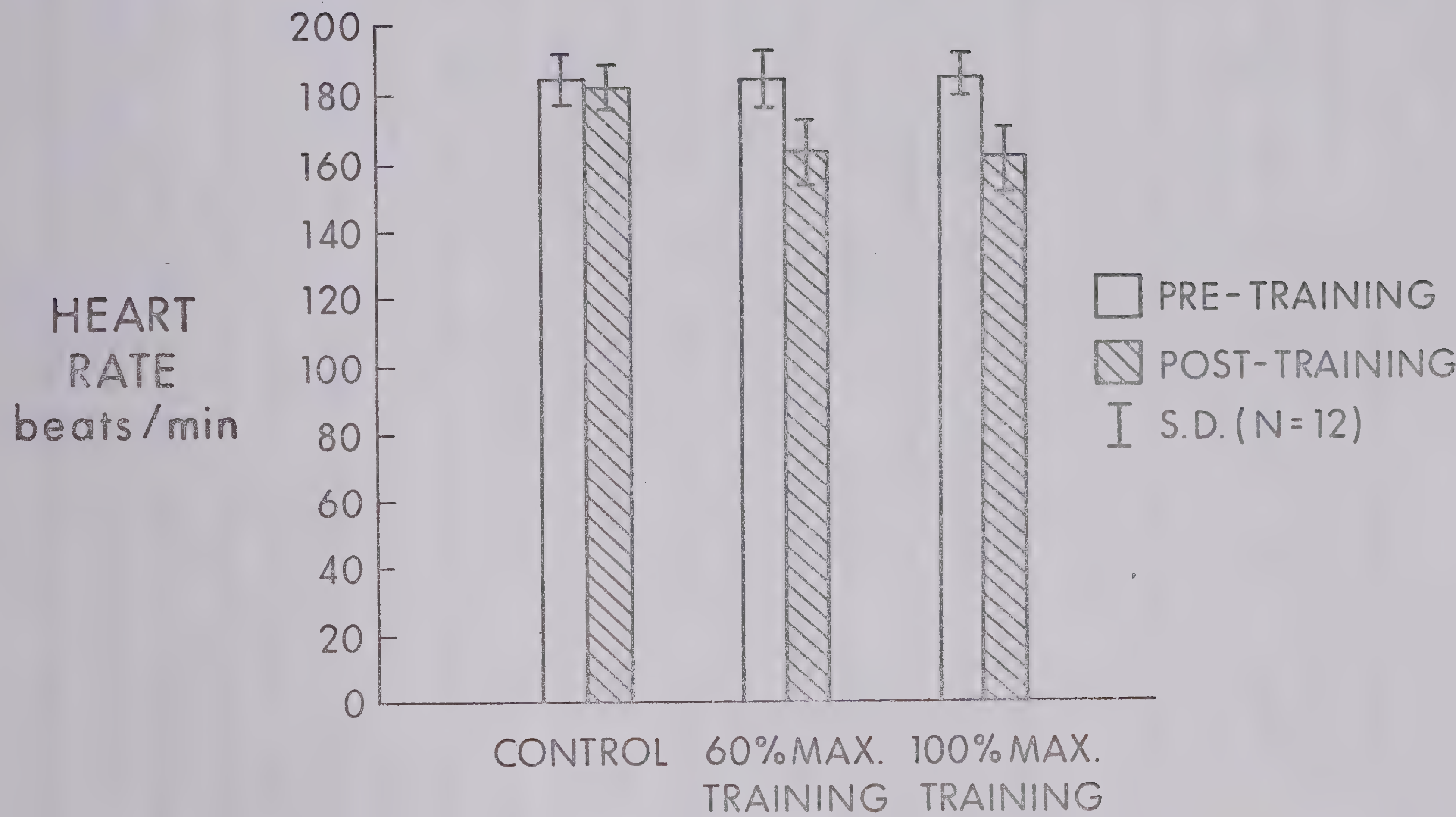
increases (0.14 and 0.11 litres per minute respectively) while the oxygen consumption for T60 remained unchanged (Table 1).

There was also no significant change in the $\dot{V}O_2$ relative to body weight. All three groups did increase slightly (2.31, 0.65, and 1.48 ml per kg per minute for groups T100, T60 and C respectively.) The body weight did not vary over the program as the weight on the initial test was 77.6 ± 7.7 kg while following training the group's mean weight was 77.3 ± 7.3 kg.

Heart Rate

Following the training program, the heart rate at the initial maximum load showed a large decrease for the two training groups compared to the control values. The heart rates decreased 24 and 21.3 beats per minute for the T100 and T60 training groups respectively, while the control group decreased only two beats per minute (Table 1 and Figure II). A three way ANOVA (Appendix A-III,i) showed significant treatment, time and treatment x time AC effects. After plotting the means of the different training groups at the pre and post training test (Figure II), it was decided to test for the simple main effects of the three treatments at post training. The one way ANOVA to test the simple main effects (Appendix A-III,ii) revealed a significant (p .01) F ratio so a Newman-Keuls test was carried out to see which, if any, means were different. The Newman-Keuls test showed the heart rates after training of both T100 and T60 were significantly (p .01) lower than the control group (Appendix A-III, iii) but there was no difference between the means of the two training groups.

FIGURE II HEART RATE AT INITIAL MAXIMUM WORK LOAD

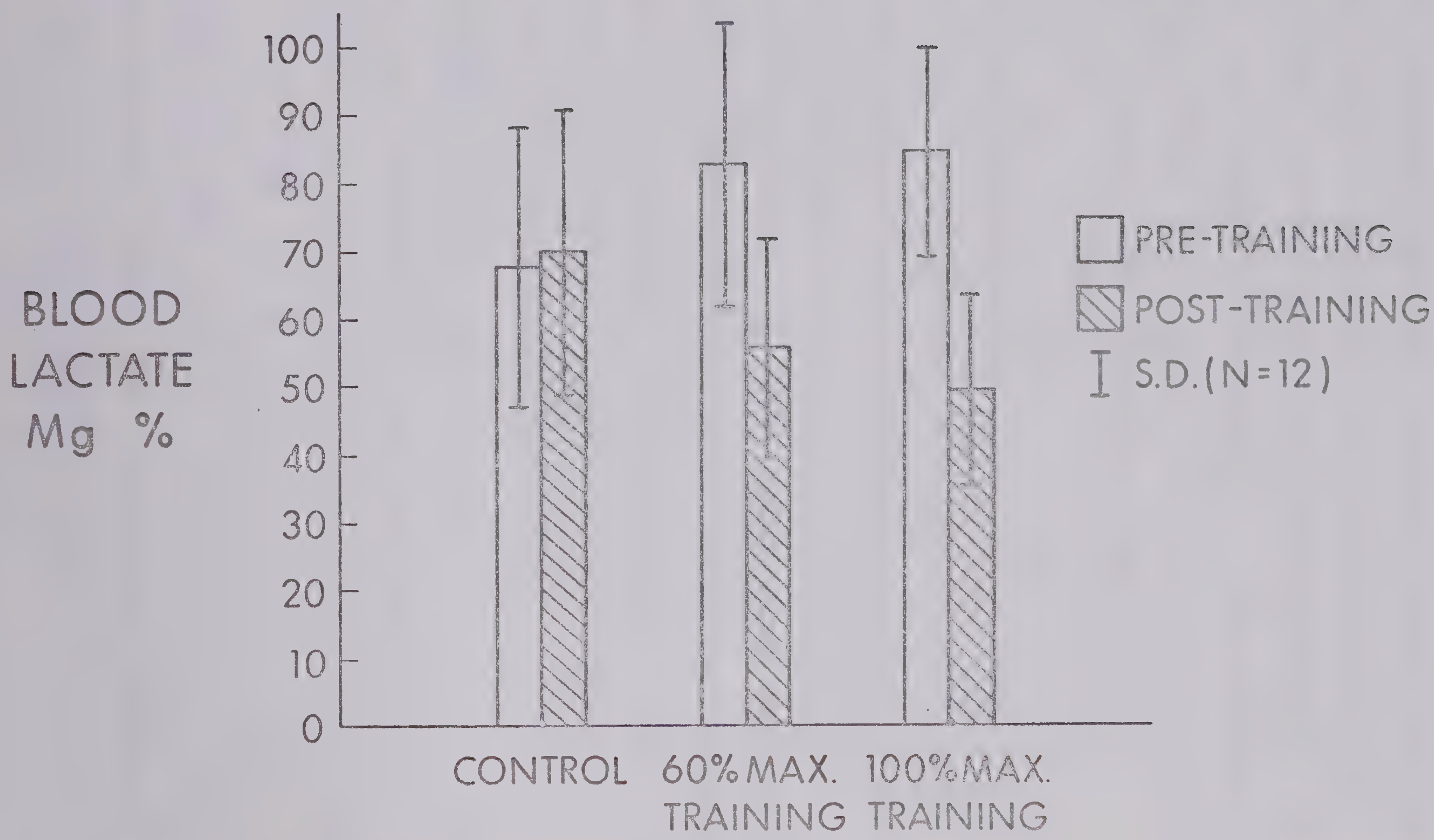


Blood Lactate Concentration

Both the T100 and T60 groups showed substantial decreases in blood lactate concentrations (35.59 and 27.25 mg% respectively) at the pre-training maximal workload over the seven week training program (Figure III). The control group, on the other hand showed a slight increase in the blood lactate concentrations at the initial maximum load (1.58 mg%).

Although the groups were equated on aerobic power after the pre-training test, they were not similar in the degree to which the anaerobic energy processes were engaged (i.e. blood lactate concentrations at initial test). The three way ANOVA (Appendix A-IV, i) revealed that the time main effects and the treatments x time interaction were significant. After plotting the means of the three treatment groups for the pre and post training tests (Figure III), two separate one way ANOVA to determine the simple main effects at BOTH the pre and post training tests were done. The analysis of variance (Appendix A-IV, ii) for all the treatments at the pre-training test resulted in a significant F ratio ($p<.05$). The Newman-Keuls test then showed that the blood lactate concentration of the two training groups at the initial maximal work load was significantly ($p<.05$) higher than the control groups. The one way ANOVA (Appendix A-V,ii) to test the simple main effects of the three treatments at the post-training test also resulted in a significant ($p<.05$) F ratio but an inspection of the means revealed that the two training groups now had lower blood lactate concentrations than the control group. That is, on the first test the two training groups were significantly higher in blood lactate concentrations

FIGURE III BLOOD LACTATE CONCENTRATION AT INITIAL MAXIMUM LOAD



at maximal work, but after seven weeks of training, they had lower blood lactate levels than the control group at the initial maximum work load. In the case of T100, the blood lactate levels were significantly (p .05) lower than the control group. The Newman-Keuls test showed (Appendix A-V, iii) no difference in blood lactate levels between the two training groups at the initial maximum work loads following the training program.

Oxygen Pulse

The oxygen pulse did not show a significant improvement at the initial maximum work load as a result of training even through the two training groups (T100 and T60 respectively) increased the millilitres of oxygen uptake per heart beat by 3.39 and 2.14 ml per beat. The control group improved slightly by 0.80 ml per beat. The three way ANOVA (Appendix A-VI, i) revealed significant (p .001) time main effects and a significant (p .02) treatment x time interaction. However, a one way ANOVA to test the simple main effects at the post training test was not significant so a statistical comparison of the means was not warranted.

Ventilatory Equivalent ($\dot{V}_E/\dot{V}O_2$)

The $\dot{V}_E/\dot{V}O_2$ decreased in all three groups (Table 1) but the differences between either or both of the training groups and the control group were not significant.

RESULTS AT MAXIMUM WORK LOADS

The pre and post training values on the various parameters at maximum work loads are tabulated in Table 2 (mean ± S.D.).

Work Loads

The work load necessary to attain maximum oxygen consumption increased in the two training groups as a result of the training program

TABLE 2

GROUP MEANS FOR VARIOUS PARAMETERS AT MAXIMUM WORK LOADS

AS OBTAINED AT PRE AND POST TRAINING TESTS

Training Program (n=12)	Work Load Kpm/min.		$\dot{V}_E$ litres/min.		VO_2 litres/min.		$\dot{V}O_2$ ml/kg/min.		HR Beats/min.		HLa mg%		$\dot{V}_E/\dot{V}O_2$		O_2pulse ml/beat	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1(T100) Mean ± S.D. (n=12)	1350 ± 230.6	1775 ± 237.9	83.6 ± 19.9	100.8 ± 15.1	3.03 ± 0.45	4.07 ± 0.47	39.5 ± 7.27	53.3 ± 8.0	185.7 ± 6.0	184.8 ± 4.5	84.9 ± 15.6	103.7 ± 20.3	27.20 ± 5.40	24.70 ± 2.5	16.35 ± 2.85	22.04 ± 2.56
2(T60) Mean ± S.D. (n=12)	1275 ± 163.1	1612.5 ± 193.2	85.6 ± 16.4	102.9 ± 17.6	3.04 ± 0.56	3.75 ± 0.49	39.3 ± 7.56	48.9 ± 6.4	184.3 ± 7.9	182.8 ± 6.6	82.6 ± 21.1	99.0 ± 26.9	29.0 ± 7.6	27.8 ± 5.4	16.58 ± 3.51	20.54 ± 2.87
3(C) Mean ± S.D. (n=12)	1350 ± 263.7	1350 ± 263.7	85.8 ± 24.2	77.9 ± 25.7	3.11 ± 0.80	3.22 ± 0.75	40.2 ± 10.02	41.7 ± 9.4	184.6 ± 7.7	183.4 ± 7.5	67.5 ± 21.2	69.5 ± 21.1	27.9 ± 6.7	24.3 ± 4.6	16.91 ± 4.40	17.71 ± 4.31

while that work load remained unchanged for the control group (Table 2). The maximum work load increased 425 kpm per minute for the T100 group and 337.5 kpm per minute for the T60 group. The three way ANOVA for maximum work loads (Appendix B-I,i) showed a significant treatment, time and a treatment x time interaction. A one way analysis of variance for the simple main effects of all treatments at the post training test resulted in a significant F ratio ($p<.01$). A Newman-Keuls test (Appendix B-I,iii) indicated that the maximum work loads for the two training groups were significantly ($p<.01$) greater than the control group after the training program and that the T100 group required significantly ($p<.05$) greater work loads to attain maximum oxygen consumption than did the T60 group.

Maximum Pulmonary Minute Ventilation ($\dot{V}_E$Max.)

The $\dot{V}_E$ max increased 17.2 and 17.3 litres per minute at STPD in the T100 and T60 groups respectively but the control group showed a decrease of 7.9 litres per minute at STPD over the seven week training program (Table 2). The three way ANOVA (Appendix B-II,i) showed a significant treatment, a time and a treatment x time interaction effect. The treatment means at the pre and post training tests were plotted (Figure V) and a one way ANOVA to determine the simple main effects of all the treatment conditions at the post training test significant ($p<.01$). A comparison between the means (Appendix B-II,iii) indicated both T100 and T60 were significantly ($p<.01$) greater than the control group after the training program.

FIGURE IV WORKLOADS AT MAXIMUM OXYGEN CONSUMPTION

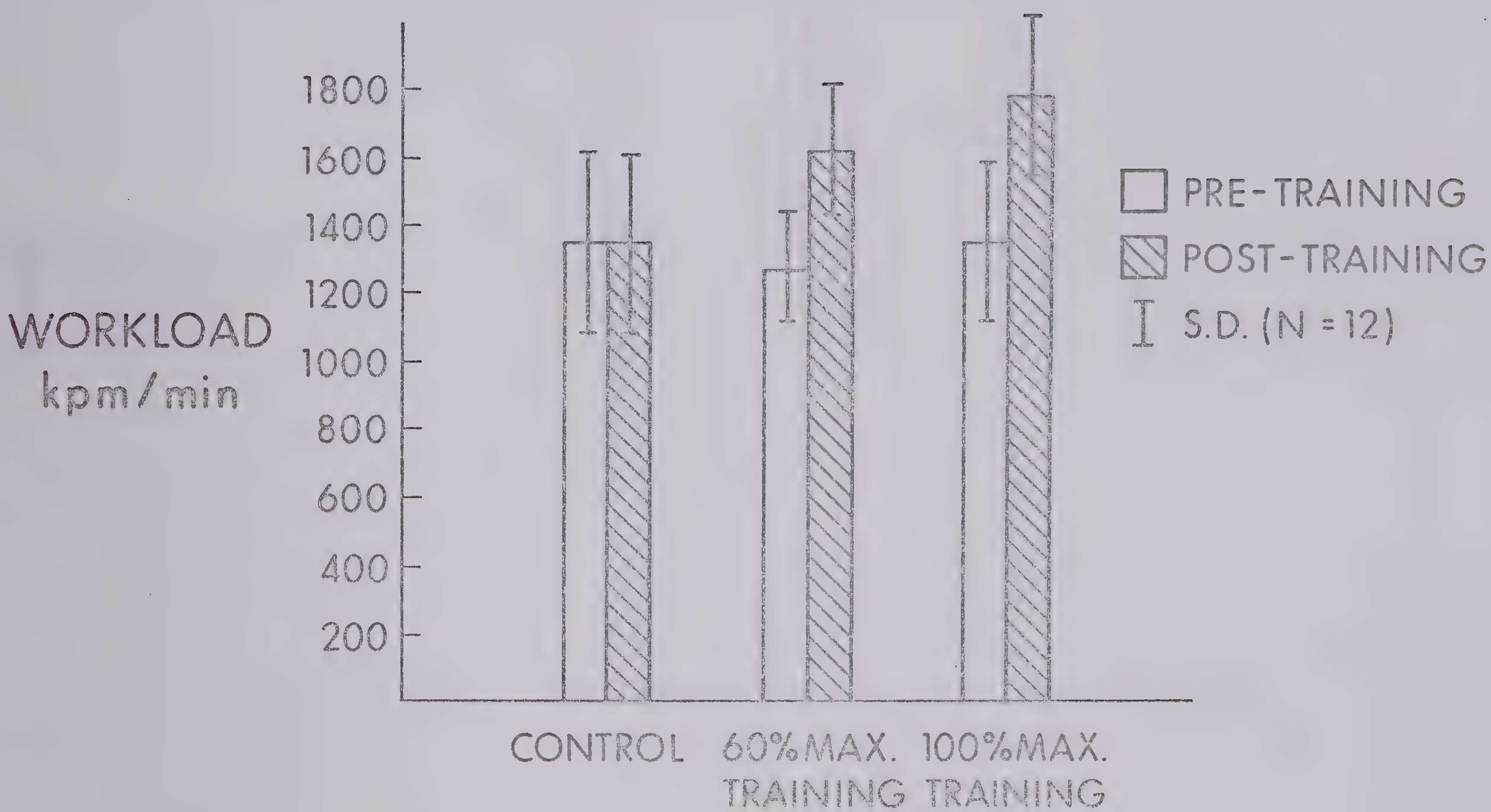
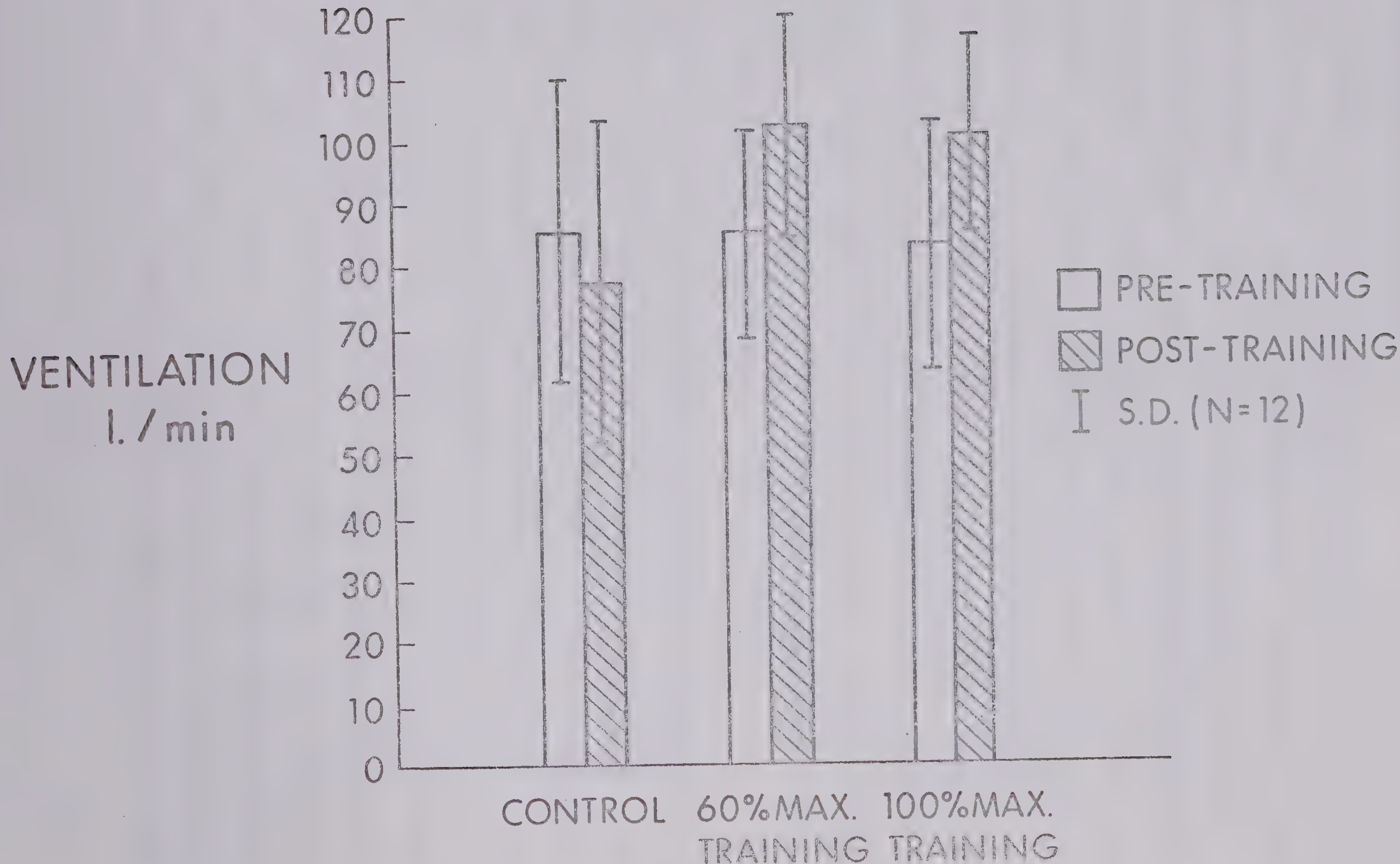


FIGURE V MAXIMUM MINUTE VENTILATION FOR THE DIFFERENT TRAINING GROUPS



<u>Maximum Oxygen Consumption</u> ($M\dot{V}O_2$)

The gross oxygen consumption (litres per minute STPD) showed a substantial increase in both the T100 and T60 groups (1.04 and 0.71 litres per minute respectively) whereas the control group displayed only a 0.11 litre increase over the seven weeks. The three way ANOVA (Appendix B-III, i) showed significant ($p<.05$) treatment effects, significant ($p<.001$) time and treatment x time interaction effects. A one way ANOVA to test for simple main effects of the treatments at the post training test was significant ($p<.01$). A subsequent comparison of the treatment means with a Newman-Keuls test (Appendix B-III,iii) showed both training groups to be significantly ($p<.01$) higher on $M\dot{V}O_2$ (litres per minute) than the control group after the training program. The difference between the two training groups, however, was not significant.

The $M\dot{V}O_2$ relative to body weight also showed a substantial increase in both the T100 and T60 training groups (13.8 and 9.6 ml per kg per minute respectively). The control group showed a modest 1.5 ml per kg per minute increase over the seven weeks. The three way ANOVA (Appendix B-IV, i) revealed highly significant ($p<.001$) treatment effects, time effects and treatment x time interaction effects. The F ratio of a one way ANOVA to test for simple main effects of all treatments at the post training test was significant ($p<.01$). A statistical comparison of the treatment means with a Newman-Keuls test (Appendix B-IV,iii) showed both the training groups were significantly ($p<.01$) higher than the control group on $M\dot{V}O_2$ (ml per kg per minute) and the T100 training group had a significantly ($p<.05$) greater $M\dot{V}O_2$ than the T60 training group.

FIGURE VI MAXIMUM OXYGEN CONSUMPTION FOR THE DIFFERENT TRAINING GROUPS

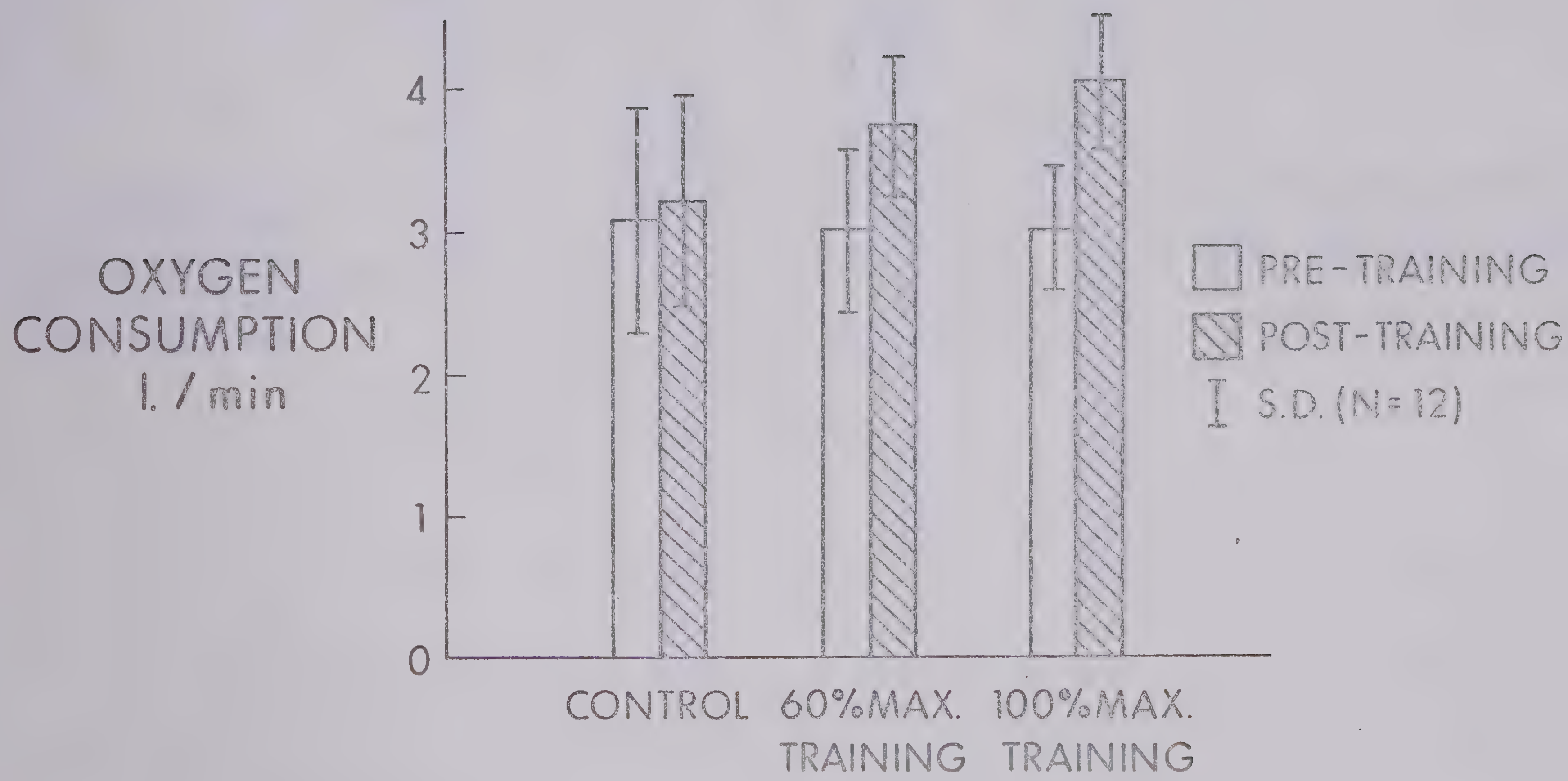
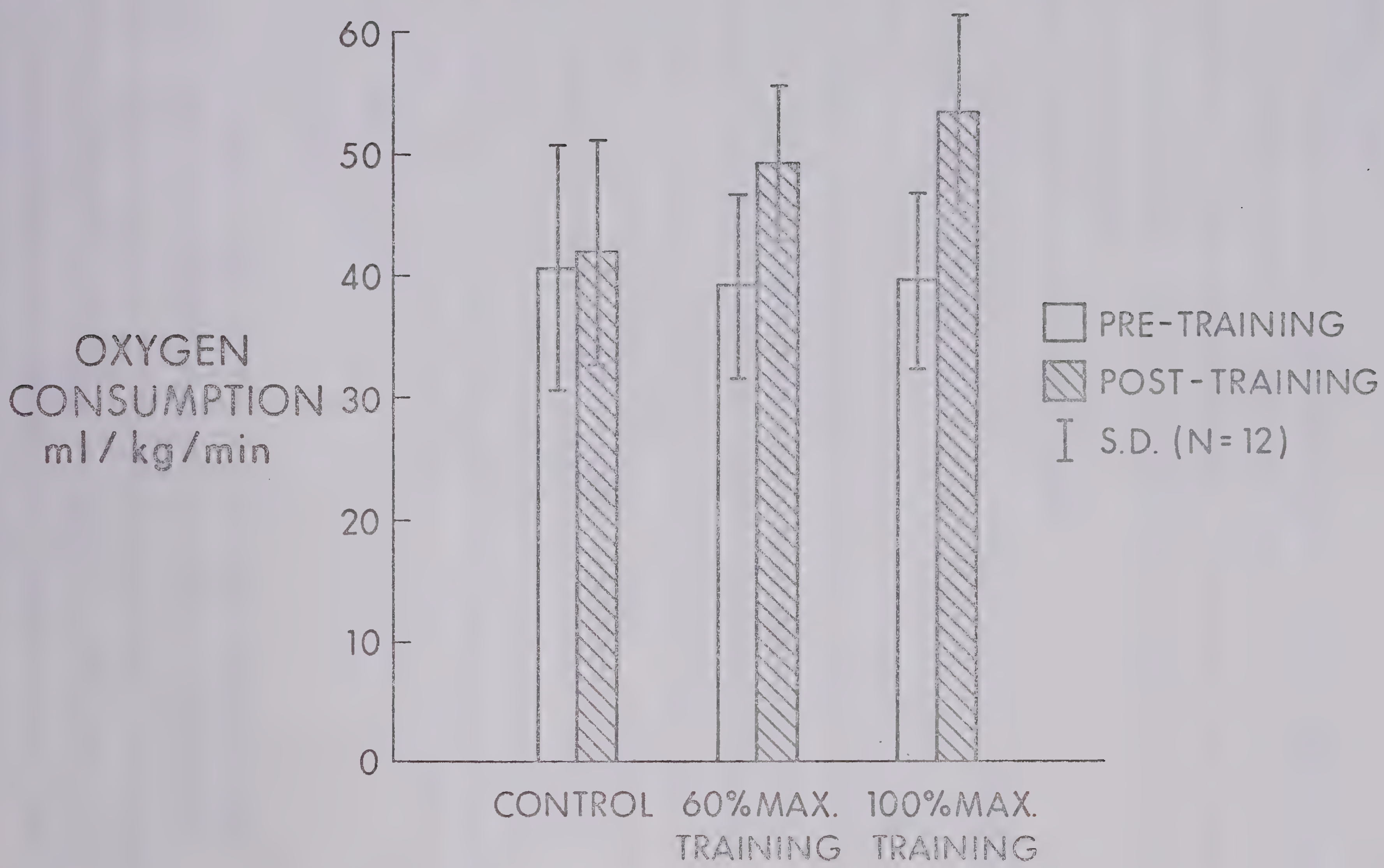


FIGURE VII MAXIMUM OXYGEN CONSUMPTION RELATIVE TO BODY WEIGHT FOR THE DIFFERENT TRAINING GROUPS



Maximum Heart Rate

The heart rate at which maximum oxygen consumption was attained did not change significantly for any of the groups over the seven week program (Table 2). None of the main effects or interaction effects from the three way ANOVA were significant (Appendix B-V,i) and hence no further analyses were warranted.

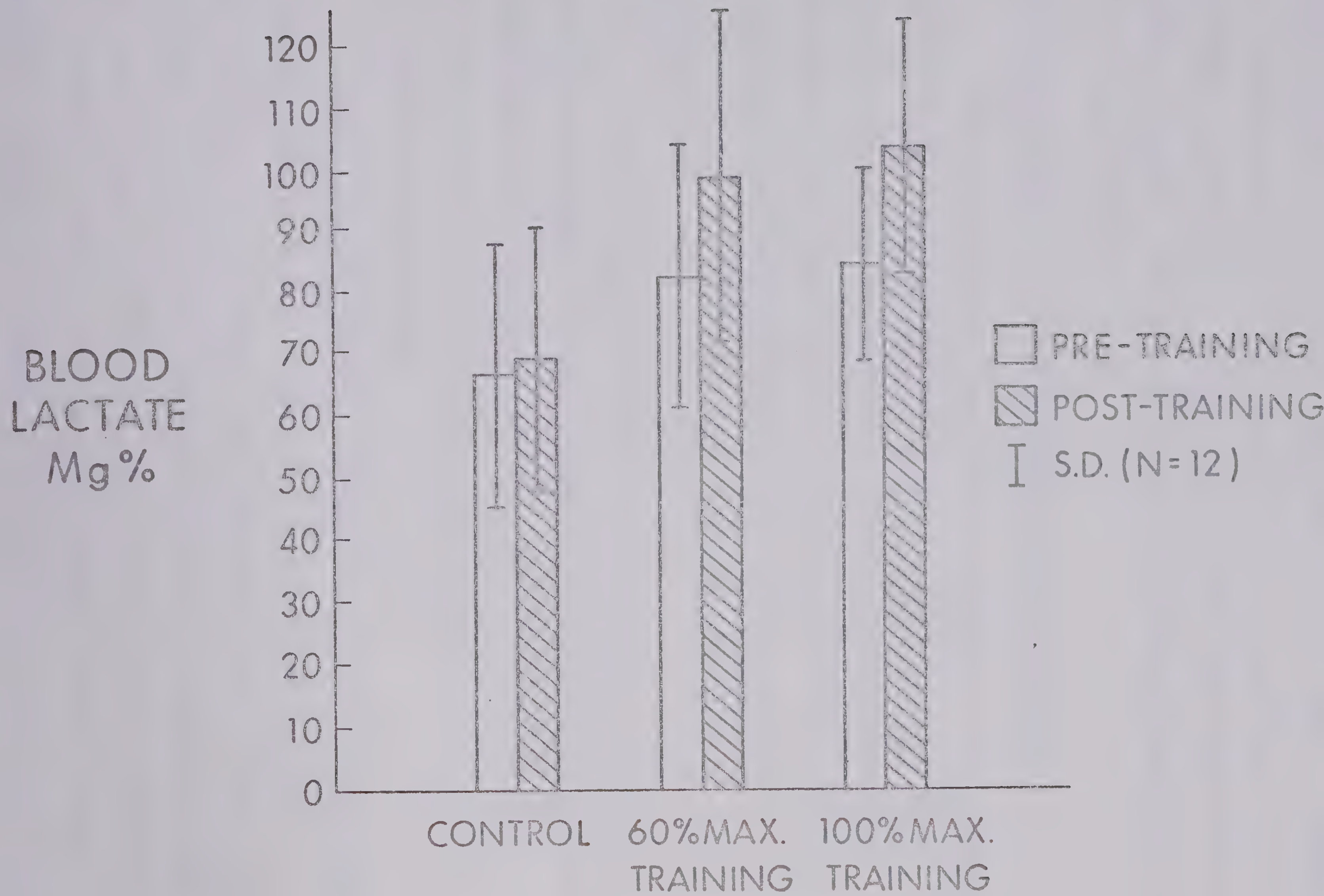
Maximum Blood Lactate Concentrations (HLa max)

As mentioned previously (p.31), the HLa max on the pre-training test was significantly ($p < .05$) higher for the two training groups than for the control group. At maximum oxygen uptake following the training program, the two training groups increased the HLa max by 19.8 and 16.4 mg% (for the T100 and T60 groups respectively) while the control group increased only 2 mg% (Figure VIII). The new difference between the training groups and the control group at the post training test was more highly significant ($p < .01$) than the pre-training test differences. However, to determine if this increased tolerance for HLa was significant, a Scheffe's contrast was done to see if the difference between the training groups and control group at the post training test were significantly greater than the difference between them on the pre-training test (Appendix B-VI,iv). These differences were not significant ($p < .05$).

Maximum Oxygen Pulse

The maximum oxygen pulse increased in the T100 and T60 groups (5.69 and 3.96 ml per heart beat respectively) while the control group increased only 0.80 ml per heart beat over the seven weeks. Statistically significant ($p < .001$) time main effects and treatment x time interaction effects from a three way ANOVA (Appendix B-VII,i) were obtained. A test for simple main effects for all treatment means at the post training test

FIGURE VIII MAXIMUM BLOOD LACTATE CONCENTRATIONS FOR THE DIFFERENT TRAINING GROUPS



(Appendix B-VII, ii) resulted in a significant ($p<.01$) F ratio. A Newman-Keuls test (Appendix B-VII, iii) showed both the training groups to have significantly ($p<.01$) greater oxygen pulses than the control group following the training program. There was no statistical difference between the two training groups on this parameter.

Ventilatory Equivalent ($M\dot{V}_E/M\dot{V}O_2$) at Maximum Oxygen Consumption

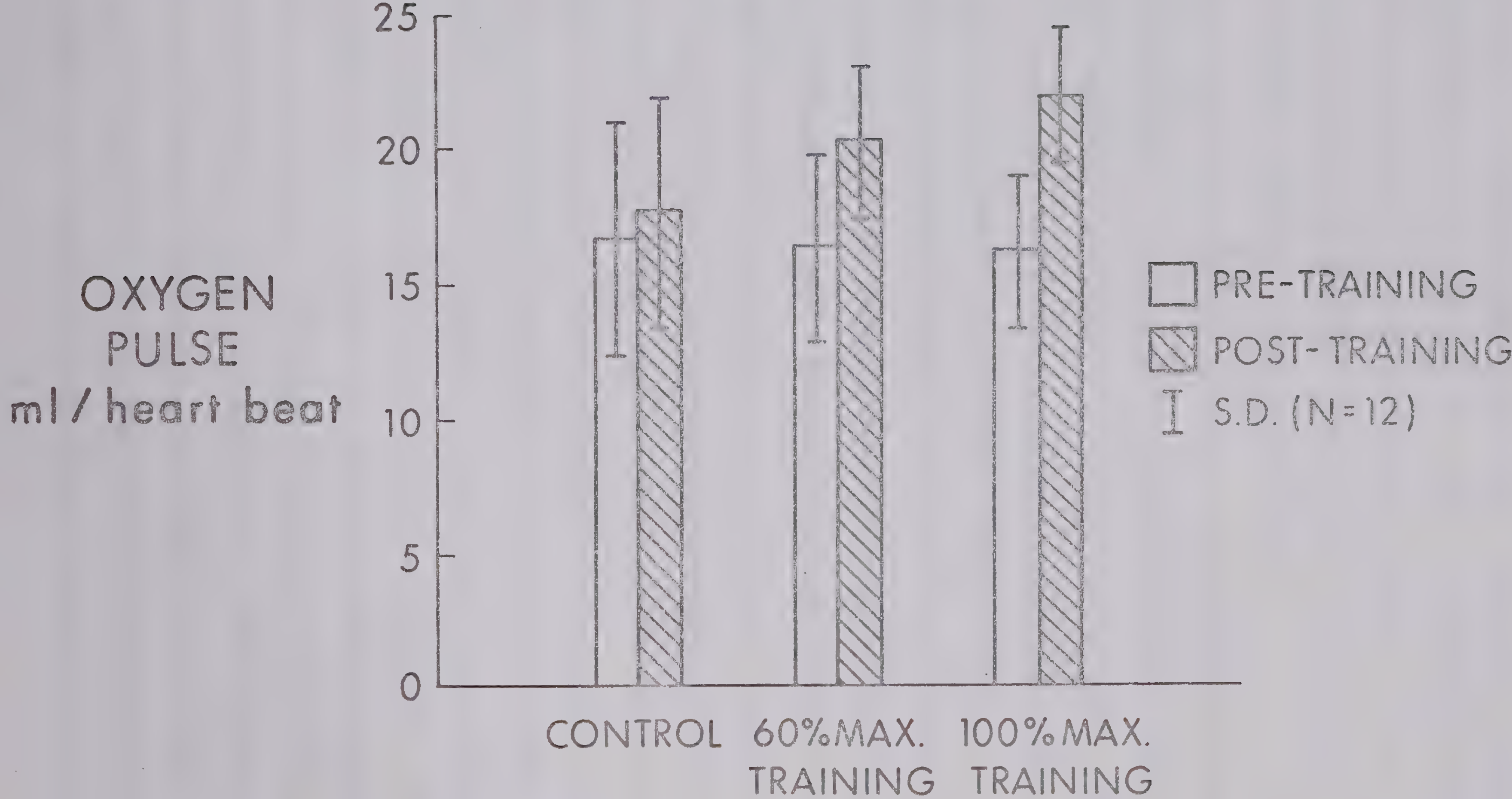
Although the $M\dot{V}_E/M\dot{V}O_2$ decreased in all groups over the training program (Table 2), the three way ANOVA (Appendix B-VIII,i) revealed no significant main effects or interaction effects so no means comparisons were warranted. Thus, there was no significant change in the ventilatory equivalent at maximal oxygen consumption.

DISCUSSION

The primary objective of endurance training is to increase the efficiency of the cardio-respiratory system and to increase the metabolic efficiency so that, following training, more work can be done with the same stress to the body or the same work can be accomplished with less stress imposed upon the individual.

It has become increasingly important, though, to be able to quantify the training stimulus so that an optimal or a maximal improvement in endurance fitness can be attained. Many studies (8,16,17,19,21,22,24,29,34, 35,43,54,55,57,58,59,63,65,67) have shown different training programs can elicit improved endurance fitness but these studies failed to quantify total work, intensity or duration of the program. Studies (68,69,73) which attempted to quantify the training stimulus failed to control total work

FIGURE IX MAXIMUM OXYGEN PULSE FOR THE DIFFERENT TRAINING GROUPS



or initial abilities or (60) confounded continuous training with interval training. The training program used in this study was designed to equate training groups on total work, initial ability and frequency of the training sessions and then to determine if intensity of the training stimulus is a primary contributor to endurance fitness.

Over the seven week program, the heart rate at the initial maximum load decreased significantly in the two training groups but not in the control. The 13% and 11% decrease in heart rate for the T100 and T60 groups respectively are in line with the result reported by many researchers(19,24,34,63,65). Ekblom (24) reported a decrease in heart rate of 26 beats per minute at a fixed submaximal work load and attributed this mainly to an increased arterio-venous oxygen difference rather than an increased stroke volume. The increased arterio-venous oxygen difference might have been due to more complete oxygen extraction in the working muscle or it could have been due to a more effective regulation of the cardiac output which would mean less blood to the inactive parts of the body. Holloszy (37) found that, training can increase the aerobic enzyme content and activity in rat muscle. This would mean that training could increase the oxygen extraction ability of the working muscle. Clausen (11) agrees with this possibility and proposes that directing of the blood from non-active to active tissues does not occur at submaximal loads as a result of training but rather the opposite occurs. In other words, because the oxygen extracting ability of the working muscle from inactive areas. The work of Ekblom et.al. (24) has shown that cardiac output does decrease at submaximal work after training due to a significant decrease in heart rate while stroke volume remained unchanged. This would lend credence to the theory that less blood is shunted into the central

circulation and that oxygen extraction is increased. This theory, however, is equivocal since Saltin et.al. (63), Hartley et.al. (34) and Saltin (65) have failed to show a decrease in cardiac output at submaximal work loads following training and have shown that the stroke volume increases at submaximal work to compensate for the decreased heart rate. Thus, the decreased heart rate at submaximal work found in this study can be attributed to either a decreased cardiac output as a result of a more efficient oxygen extraction process at the working muscle or as a result of an increased stroke volume probably due to an increased force of contraction or a combination of both effects. Although the increase in oxygen pulse at the initial maximum load following training was not statistically significant, there was an increase (Table 1). Since the oxygen consumption did not change at the initial maximum load, the small increases in oxygen pulse were due to the decreased heart rate. Thus the increased oxygen pulse fails to clarify the controversy because it could have been due to either an increased arterio-venous oxygen difference or an increased stroke volume. The difference between the T100 training groups on heart rates at initial maximum work load were not different and hence it seems probable that as long as the intensity of training is greater than 60% of maximal aerobic power, optimum decreases in heart rate at a submaximal load can be achieved. Since 60% of maximal aerobic power was the lowest relative training work load which was used, no inferences can be made regarding lesser relative loads. Thus if a decreased cardiac work load is the objective of a training regimen and the time for each training session is limited, then high intensity work for a short duration could be prescribed for healthy people. However, if limited time is not a consideration, and the high intensity work is not desirable, a relative work load of 60% of maximum

aerobic power could be suggested with an expected decrease in heart rate at submaximal work of the same magnitude as would result with the high intensity program.

The decreases in blood lactate at the initial maximum work load, following training, of 42% and 32% for the T100 and T60 groups respectively are similar to the results obtained by Robinson and Harmon (59), Saltin et.al. (65), and Ekblom et.al. (24). Åstrand and Rodahl (5) interpret this decrease as being a result of a more effective oxygen transport during the beginning of work leading to a diminished anaerobic energy yield. Williams et.al. (86) showed that training can increase the percentage of maximal oxygen consumption at which anaerobic metabolism occurs. The work of Saltin et.al. (65) Hartley et.al. (34) and Ekblom et.al. (24) would suggest that the increased arterio-venous oxygen difference could account for the decreased anaerobic metabolism at the initial maximum load following training. Although the pulmonary ventilation did not significantly decrease at the initial maximum load, it is apparent (Figure I) that there was a drop in the ventilation due to training. Åstrand and Rodahl (5) report that this drop is generally associated with a decreased rate of respiration with no change in the depth of breathing. During work at which lactate is being produced, the pH of the blood falls slightly and, as well, the pCO_2 increases. The respiratory rate is increased by a decreased pH and/or increased pCO_2 (5). Since the blood lactate was lower after training in the two training groups, the respiratory rate would be decreased resulting in the observed decrease in pulmonary ventilation. The decrease in blood lactate at initial maximum load following training was slightly greater in the T100 group than in the

T60 group (Figure III) which could have resulted in the slightly greater decrease in $\dot{V}_E$ for the T100 group (Figure I). Since the lactate production at submaximal work loads is a direct result of an insufficient aerobic energy supply, the training program which could improve the efficiency of the aerobic system to the greatest extent should decrease the involvement of the anaerobic energy processes to the greatest extent. The T100 training group showed a larger decrease in blood lactate production at the initial maximum work load after training than did the T60 group (Figure III) although this difference was not statistically significant. The T100 training group also demonstrated a significantly ($p<.05$) greater improvement in $M\dot{V}O_2$ (ml per kg per minute) which suggests that the efficiency of the oxygen utilization and transport systems at maximal work was improved more by the high intensity work. Although relating this increased efficiency at maximal work to an increased efficiency at submaximal work may not be valid, the results on oxygen pulse at initial maximum work load might indicate that it is legitimate. The T100 group showed a greater increase in oxygen pulse at the initial maximum work load than did the T60 group (Table 1) although not statistically significant. This would mean that per heart beat, the oxygen uptake and utiliziation improved more at the initial maximum work load with the high intensity rather than the aerobic type of training.

Since the oxygen consumption at the initial maximum work load was not changed following training (Table 1), the training program did not improve the efficiency of bicycle riding.

The ventilatory equivalent ($\dot{V}_E/\dot{V}O_2$) at both the initial maximum load and the maximum work following training did not change. This substantiates the work of Saltin et.al. (63) and Saltin et.al. (65) who reported

that changes in pulmonary ventilation were accompanied by proportional changes in oxygen consumption resulting in the ratio being unchanged. This would indicate that adaptations to the training stimulus occur in the circulatory system and/or metabolic processes and do not affect the pulmonary efficiency per se.

The two training groups did demonstrate an increased lactic acid tolerance (maximum blood lactate levels increased by 23.3% and 19.8% for the T100 and T60 groups respectively) over the training period (Figure VIII). It seems relevant that there was very little difference between the two training groups. Because the T100 group was taxing the anaerobic energy processes to a large extent throughout the training and the T60 group was working mostly aerobically, it might have been expected that the ability to tolerate the anaerobic metabolite (lactic acid) would have been greater in the T100 group. This does not appear to be the case and hence, through training at 60 up to 100% of maximal aerobic power, a similar tolerance to lactic acid can be achieved.

The increases in $M\dot{V}O_2$ (ml per kg per minute) of 33% and 24% (Figure VII) for the T100 and T60 groups respectively are higher than those found by many researchers (22,24,34,58,65). They are, however, very similar to the results obtained by Saltin et.al. (63) and Pollock, Cureton and Greninger (57) and are somewhat lower than the findings of Naughton and Balke (54) and Cureton and Phillips (17). It is very difficult to compare the magnitude of changes in the different studies with the changes reported in this study because in the other studies there has been very little effort or concern in attempting to precisely quantify the training programs in terms

of initial fitness levels, intensity of the training, frequency of the sessions, duration of each session, and total work output. Shephard (73) reported the greatest improvement in $M\dot{V}O_2$ is attained with a program of maximum intensity, frequency and duration of effort. This study, however, failed to equate total work and therefore the increased total work output by the group which trained at the greatest intensity, frequency and duration could have accounted for his higher $M\dot{V}O_2$ values. In this study where frequency and total work were equated in both training groups, the fact that the T100 group improved significantly ($p<.05$) more than the T60 group on $M\dot{V}O_2$ (ml per kg per minute) indicates that intensity of the training stimulus is the main factor in improving endurance fitness as measured by maximum oxygen consumption.

Although the improvement in maximum oxygen pulse between the two training groups over the training program was not significant ($p<.05$) the T100 group did improve on this measure of cardio-pulmonary efficiency by a greater margin than did the T60 group (Figure IX).

Along with an increased ability to take up, transport, and utilize oxygen, an increased capacity to perform physical work is a primary requisite of an endurance training program. Both the T100 and T60 training groups increased their capacity to perform physical work over the seven weeks of training. The high intensity group (T100), though, achieved a significantly ($p<.05$) greater capacity than did the group which trained at a lower intensity (T60). This increased capacity in the T100 group is probably

highly related to its higher $M\dot{V}O_2$ following the training program.

Thus it would seem in a training period extending over seven weeks and with the total work output, and initial ability equated the intensity of the training program relative to maximal aerobic power is of primary importance in producing optimal endurance fitness improvement.

CHAPTER V

SUMMARY AND CONCLUSIONS

SUMMARY

Thirty six volunteer subjects (mean age 27.9 years) were blocked into four levels of initial fitness as determined by their maximum oxygen consumption in ml per kg per minute. The nine subjects in each fitness level were randomly assigned to one of three treatment groups. Thus the three groups were equated on initial fitness as measured by maximum oxygen consumption relative to body weight. The first treatment group (T100) trained at 100% of their $M\dot{V}O_2$; the second treatment group (T60) trained at work loads which produced 60% of their $M\dot{V}O_2$; and the third treatment group (C) served as a control. The training program consisted of three training sessions per week for seven weeks. Subjects of similar initial fitness and body weight in the two different training groups (T100 and T60) were yoked together as partners. The T100 group trained each session at 100% of their $M\dot{V}O_2$ for as long as they could continue on the bicycle ergometer. The subjects in T60 did the same total work as their partner only at 60% of their $M\dot{V}O_2$. Thus the total work performed in each session and the total work performed over the seven weeks was equal for both groups. Even though subjects within the same training group performed different absolute work loads, the relative work load within each group was the same (i.e. either 100% of $M\dot{V}O_2$ or 60% of $M\dot{V}O_2$) during each training session. Testing was done prior to and following the seven weeks of training.

The heart rates at the initial maximum work load were significantly ($p<.01$) lower for the two training groups compared to the control group following the seven week program. The difference between the T100 and T60 groups, however, was not significant.

Blood lactate concentrations for the two training groups were significantly lower than the control after training at the initial maximum work load. The difference between the two training groups, however, was not significant.

Maximum pulmonary ventilation was significantly ($p<.01$) greater in the two training groups compared to the control group after training but the difference between the two training groups was not significant.

Blood lactate concentrations at maximum oxygen consumption were higher in the two training groups than in the control following training but this difference was not significant ($p<.05$).

The work load which produced maximum oxygen consumption was significantly ($p<.01$) greater for the two training groups compared to the control group following the training program. The T100 group also required a significantly ($p<.05$) greater work load than did the T60 group to produce $M\dot{V}O_2$ following the training.

Maximum oxygen consumption in the two training groups was significantly ($p<.01$) higher following the training than the control group and the T100 group was significantly ($p<.05$) greater than the T60 group.

Both training groups had significantly ($p<.01$) higher maximum oxygen pulse values following training than did the control group but the

difference between the two training groups was not significant ($p<.05$).

CONCLUSIONS

Since the two training groups showed similar substantial reductions in heart rate at the initial maximum work load following training, it seems probable that any intensity of training (from 60% up to 100% of $M\dot{V}O_2$ would be equally suitable in reducing cardiac work at submaximal work loads.

Since maximum oxygen consumption relative to body weight has been proposed as the best single measure of endurance fitness, and the T100 group showed a significantly greater ($p<.05$) improvement on this parameter over the T60 group, it would be appropriate to suggest that intensity of the training is the primary contributor to an improved oxygen transport system. Because the work load necessary to ellicit maximum oxygen consumption was also significantly ($p<.05$) higher in the T100 group following training, the increased intensity also seems to improve, to a greater extent, the capacity to do physical work.

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APPENDIX A

STATISTICAL ANALYSIS OF DATA OBTAINED AT INITIAL MAXIMUM WORK LOADS PRIOR TO AND FOLLOWING TRAINING

Appendix A-II

i)

THREE WAY ANALYSIS OF VARIANCE FOR OXYGEN CONSUMPTION

AT INITIAL MAXIMUM LOAD IN LITRES PER MINUTE

Summary Table:

Source	SS	df	MS	F	P
Between Subjects	22.37	35			
A	0.20	2	0.10	0.59	<.57
B	15.69	3	5.23	30.57	<.001
AB	2.364	6	0.39	2.30	<.07
subj. w. grps.	4.11	24	0.17		
Within Subjects	2.63	36			
C	0.16	1	0.16	1.98	<.18
AC	0.08	2	0.04	0.50	<.62
BC	0.06	3	0.02	0.26	<.86
ABC	0.37	6	0.06	0.76	<.61
Cx. subj. w. grps.	1.96	24	0.08		

Appendix A-I

i)

THREE WAY ANALYSIS OF VARIANCE FOR PULMONARY MINUTE VENTILATION AT INITIAL MAXIMUM LOAD IN LITRES PER MINUTE

Summary Table:

Source	SS	df	MS	F	P
Between Subjects	21532.44	35			
A	698.63	2	349.31	1.67	<.21
B	11935.50	3	3978.50	18.99	<.001
AB	3870.75	6	645.13	3.08	<.03
subj. w. grps.	5028.56	24	209.48		
Within Subjects	7361.06	36			
C	3306.00	1	3306.00	25.21	<.001
AC	282.75	2	141.38	1.08	<.36
BC	393.38	3	131.13	1.00	<.41
ABC	231.56	6	38.59	0.29	<.94
Cx. subj. w. grps.	3147.38	24	131.14		

Appendix A-III

i)

THREE WAY ANALYSIS OF VARIANCE FOR HEART RATE

AT INITIAL MAXIMUM LOAD IN BEATS PER MINUTE

Summary Table:

Source	SS	df	MS	F	P
Between Subjects	4705.00	35			
A	1580.00	2	790.00	8.15	<.01
B	446.00	3	148.67	1.53	<.24
AB	352.00	6	58.67	0.61	<.73
subj. w. grps.	2327.00	24	96.96		
Within Subjects	7496.00	36			
C	4465.00	1	4465.00	219.59	<.001
AC	1723.00	2	861.50	42.37	<.001
BC	447.00	3	149.00	7.33	<.01
ABC	373.00	6	62.17	3.06	<.03
Cx. subj. w. grps.	488.00	24	20.33		

ii)

TEST FOR SIMPLE MAIN EFFECTS FOR HEART RATE

AT INITIAL MAXIMUM LOAD BETWEEN TREATMENTS AT POST-TRAINING TEST

Summary Table:

Source	df	MS	F	${}_{24}^{2}F$ crit
Between	2	1645.59	28.06	α .01=5.61 α .05=3.40
Within	24	58.65		

Appendix A-III

iii)

NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS

FOR HEART RATE AT INITIAL MAXIMUM LOAD - POST-TRAINING

MEANS	3(C) 182.58	2(T60) 163.00	1(T100) 161.67
1(T100) 161.67	20.92 **	1.33	
2(T60) 163.00	19.58 **		
3(C) 182.58			

** significant at α.01

Critical Differences:

		r=2	r=3
$q_{.99}(r,24)\sqrt{MS\ within/n}$	=	8.75	10.03
$q_{.95}(r,24)\sqrt{MS\ within/n}$		6.45	7.80

Appendix A-IV

i)

THREE WAY ANALYSIS OF VARIANCE FOR BLOOD LACTATE CONCENTRATION AT INITIAL MAXIMUM LOAD IN MILLIGRAMS PER CENT.

Summary Table:

Source	SS	df	MS	F	P
Between Subjects	17384.44	35			
A	41.38	2	20.69	0.05	<.96
B	5479.63	3	1826.54	4.32	<.02
AB	1724.44	6	287.41	0.68	<.67
Subj. w. grps.	10139.00	24	422.46		
Within Subjects	17327.50	36			
C	7503.19	1	7503.19	56.36	<.001
AC	4564.25	2	2282.13	17.14	<.001
BC	145.13	3	48.38	0.36	<.79
ABC	1919.94	6	319.99	2.40	<.06
Cx . subj.w. grps.	3195.00	24	133.13		

ii)

TEST FOR SIMPLE MAIN EFFECTS FOR BLOOD LACTATE CONCENTRATIONS (Mg%) AT INITIAL MAXIMUM LOAD BETWEEN TREATMENTS AT PRE-TRAINING TEST

Summary Table:

Source	df	MS	F	${}^{2}_{24}F$ crit.
Between	2	1072.56	3.86	$\alpha .01 = 5.61$ $\alpha .05 = 3.40$
Within	24	277.78		

Appendix A-IV

iii)

NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS FOR BLOOD LACTATE CONCENTRATION (Mg%) AT INITIAL MAXIMUM LOAD ON PRE-TRAINING TEST

GROUP MEANS	1(T100) 84.92	2(T60) 82.58	3(C) 67.50
3(C) 67.50	17.42 *	15.08 *	
2(T60) 82.58	2.33		
1(T100) 84.92			

* significant at α.05

critical differences:	r=2	r=3
q.99 (r,24)√ MS within/n	19.05	21.84
q.95 (r,24)√ MS within/n	14.05	16.98

Appendix A-V

i)

THREE WAY ANALYSIS OF VARIANCE FOR BLOOD LACTATE CONCENTRATION AT INITIAL MAXIMUM LOAD IN MILLIGRAMS PERCENT

Summary Table:

Source	SS	df	MS	F	P
Between Subjects	17384.44	35			
A	41.38	2	20.69	0.05	$<.95$
B	5479.63	3	1826.54	4.32	$<.02$
AB	1724.44	6	287.41	0.68	$<.67$
Subj. w. grps.	10139.00	24	422.46		
Within Subjects	17327.50	36			
C	7503.19	1	7503.19	56.36	$<.001$
AC	4564.25	2	2282.13	17.14	$<.001$
BC	145.13	3	48.38	0.36	$<.79$
ABC	1919.94	6	320.00	2.40	$<.06$
Cx. subj. w. grps.	3195.00	24	133.13		

ii)

TEST FOR SIMPLE MAIN EFFECTS FOR BLOOD LACTATE CONCENTRATIONS (Mg%) AT INITIAL MAXIMUM LOAD BETWEEN TREATMENTS AT POST-TRAINING TEST

Summary Table:

Source	df	MS	F	${}_{24}^{2}F$ crit.
Between	2	1230.22	4.43	$\alpha .01=5.61$ $\alpha .05=3.40$
Within	24	277.80		

Appendix A-V

iii)

NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS FOR BLOOD LACTATE CONCENTRATIONS (Mg%) AT INITIAL MAXIMUM LOAD ON POST-TRAINING TEST

GROUP MEANS	3(C) 69.08	2(T60) 55.33	1(T100) 49.33
1(T100) 49.33	19.75 *	6.00	
2(T60) 55.33	13.75		
3(C) 69.08			

* significant at α.05

Critical Differences:	r=2	r=3
$q_{.99}$ (r,24) $\sqrt{MS\ within/n}$	19.05	21.84
$q_{.95}$ (r,24) $\sqrt{MS\ within/n}$	14.05	16.98

Appendix A-VI

i)

THREE WAY ANALYSIS OF VARIANCE FOR OXYGEN PULSE AT INITIAL MAXIMUM LOAD IN MILLILITRES PER HEART BEAT

Summary Table:

Source	SS	df	MS	F	P
Between Subjects	758.55	35			
A	6.58	2	3.29	0.49	<.63
B	501.29	3	167.09	24.70	<.001
AB	88.30	6	14.72	2.18	<.09
Subj. w. grps.	162.37	24	6.77		
Within Subjects	170.47	36			
C	79.96	1	79.96	37.00	<.001
AC	20.22	2	10.11	4.68	<.02
BC	6.82	3	2.27	1.05	<.39
ABC	11.61	6	1.93	0.90	<.51
Cx. subj. w. grps.	51.87	24	2.16		

Appendix A-VII

i)

THREE WAY ANALYSIS OF VARIANCE FOR VENTILATORY EQUIVALENT
IN LITRES OF VENTILATION PER LITRE OF OXYGEN
CONSUMED PER MINUTE AT INITIAL MAXIMUM WORKLOAD

Summary Table:

Source	SS	df	MS	F	P
Between Subjects	10.90	35			
A	0.65	2	0.32	1.14	<.34
B	2.60	3	0.87	3.04	<.05
AB	0.81	6	0.14	0.47	<.83
Subj. w. grps.	6.84	24	0.29		
Within Subjects	13.98	36			
C	5.31	1	5.31	17.71	<.001
AC	0.28	2	0.14	0.47	<.64
BC	0.57	3	0.19	0.63	<.61
ABC	0.64	6	0.11	0.35	<.90
C x subj. w. grps.	7.19	24	0.30		

APPENDIX B

STATISTICAL ANALYSIS OF DATA OBTAINED AT MAXIMAL WORK LOADS PRIOR TO AND AFTER TRAINING

Appendix B-I

i)

THREE WAY ANALYSIS OF VARIANCE FOR WORK LOADS

AT MAXIMUM IN KILOPOND METERS PER MINUTE

Summary Table:

Source	SS	df	MS	F	P
Between Subjects	3760912.0	35			
A	544400.00	2	272200.00	4.68	<.02
B	1330960.00	3	443653.31	7.63	<.001
AB	490490.00	6	81746.63	1.41	<.25
subj. w. grps.	1395072.00	24	58128.00		
Within Subjects	1991216.00	36			
C	1162800.00	1	1162800.00	185.85	<.001
AC	604336.00	2	302168.00	48.30	<.001
BC	18384.00	3	6128.00	0.98	<.42
ABC	55728.00	6	9288.00	1.48	<.23
C x subj. w. grps	150160.00	24	6256.66		

ii)

TEST FOR SIMPLE MAIN EFFECTS FOR MAXIMUM WORK LOADS (kpm/min)

BETWEEN TREATMENTS AT POST-TRAINING TEST

Source	df	MS	F	${}_{24}^{2}F$ crit.
Between	2	551864.0	17.14	α<.01=5.61 α<.05=3.40
Within	24	32192.35		

Appendix B-I

iii)

NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS

FOR MAXIMAL WORK LOADS (kpm/min) AT POST-TRAINING TEST

GROUP MEANS	1(T100) 1775.0	2(T60) 1612.5	3(C) 1350.0
3(C) 1350.0	425.0 **	262.5 **	
2(T60) 1612.5	162.5 *		
1(T100) 1775.0			

** significant at $\alpha .01$
* significant at $\alpha .05$

Critical Differences:	r=2	r=3
$q_{.99}(r,24)\ \sqrt{MS\ within/n}$	205.09	235.13
$q_{.95}(r,24)\ \sqrt{MS\ within/n}$	151.23	182.82

Appendix B-II

i)

THREE WAY ANALYSIS OF VARIANCE FOR MAXIMUM PULMONARY

MINUTE VENTILATION IN LITRES PER MINUTE (STPD)

Summary Table:

Source	SS	df	MS	F	P
Between Subjects	24143.81	35			
A	2129.69	2	1064.84	3.63	$< .05$
B	11295.44	3	3765.15	12.83	$< .001$
AB	3676.81	6	612.80	2.09	$< .10$
Subj. w. grps.	7041.88	24	293.41		
Within Subjects	8250.38	36			
C	1406.88	1	1406.88	10.01	$< .01$
AC	2532.38	2	1266.19	9.01	$< .01$
BC	290.38	3	96.79	0.69	$< .57$
ABC	647.38	6	107.89	0.77	$< .61$
C x subj. w. grps	3373.50	24	140.56		

ii)

TEST FOR SIMPLE MAIN EFFECTS FOR MAXIMUM PULMONARY VENTILATION

(litres/minute at STPD) BETWEEN TREATMENTS

AT POST TRAINING TEST

Summary Table:

Source	df	MS	F	${}^{2}_{24}F$ crit.
Between	2	2312.5	10.66	$\alpha .01=5.61$ $\alpha .05=3.40$
Within	24	217		

iii)

NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS FOR MAXIMUM PULMONARY VENTILATION (litres/minute at STPD) at POST TRAINING TEST

GROUP MEANS	2(T60) 102.90	1(T100) 100.77	3(C) 77.86
3(C) 77.86	25.04 **	22.90 **	
1(T100) 100.77	2.138		
2(T60) 102.90			

** significant at α.01

Critical Differences:	r=2	r=3
$q_{.99}(r,24)\sqrt{MS\ within/n}$	16.83	19.30
$q_{.95}(r,24)\sqrt{MS\ within/n}$	12.41	15.00

Appendix B-III

i)

THREE WAY ANALYSIS OF VARIANCE FOR MAXIMUM OXYGEN CONSUMPTION IN LITRES PER MINUTE (STPD)

Summary Table:

Source	SS	df	MS	F	P
Between Subjects	22.76	35			
A	1.74	2	0.87	3.53	< .05
B	12.23	3	4.08	16.54	< .001
AB	2.88	6	0.48	1.94	< .12
Subj. w. grps.	5.92	24	0.25		
Within Subjects	12.77	36			
C	7.02	1	7.02	68.17	< .001
AC	2.70	2	1.36	13.13	< .001
BC	0.43	3	0.14	1.40	< .27
ABC	0.14	6	0.02	0.23	< .97
C x subj. w. grps.	2.47	24	0.10		

ii)

TEST FOR SIMPLE MAIN EFFECTS FOR MAXIMUM OXYGEN CONSUMPTION (litres/minute at STPD) BETWEEN TREATMENTS AT POST TRAINING TEST

Summary Table:

Source	df	MS	F	${}_{24}^{2}F$ crit.
Between	2	2.19	12.51	α.01=5.61 α.05=3.40
Within	24	0.175		

iii)

NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS FOR MAXIMUM OXYGEN CONSUMPTION (Litres/minute at STPD) AT POST TRAINING TEST

GROUP MEANS	1(T100) 4.07	2(T60) 3.75	3(C) 3.22
3(C)	0.85 **	0.53 **	
2(T60)	0.32		
1(T100)			

** significant at α .01

Critical Differences:	r=2	r=3
$q_{.99}(r,24)\sqrt{MS\ within/n}$	0.48	0.54
$q_{.95}(r,24)\sqrt{MS\ within/n}$	0.35	0.42

Appendix B-IV

i)

THREE WAY ANALYSIS OF VARIANCE FOR MAXIMUM OXYGEN CONSUMPTION IN MILLILITRES PER KILOGRAM OF BODY WEIGHT PER MINUTE

Summary Table:

Source	SS	df	MS	F	P
Between Subjects	4306.13	35			
A	359.44	2	179.72	9.51	$<.001$
B	3266.50	3	1088.83	57.60	$<.001$
AB	226.50	6	37.75	2.00	$<.11$
subj. w. grps.	453.69	24	18.90		
Within Subjects	2203.13	36			
C	1237.25	1	1237.25	69.44	$<.001$
AC	470.63	2	235.31	13.21	$<.001$
BC	38.25	3	12.75	0.72	$<.56$
ABC	29.38	6	4.90	0.27	$<.95$
C x subj. w. grps.	427.63	24	17.82		

ii)

TEST FOR SIMPLE MAIN EFFECTS FOR MAXIMUM OXYGEN CONSUMPTION (ml/kg/minute at STPD) BETWEEN TREATMENTS AT POST TRAINING TEST

Source	df	MS	F	${}^{2}_{24}F$ crit
Between	2	412.34	22.43	$\alpha .01=5.61$ $\alpha .05=3.40$
Within	24	18.36		

iii)

NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS FOR MAXIMUM OXYGEN CONSUMPTION (ml/kg/minute at STPD) AT POST TRAINING TEST

GROUP MEANS	1(T100) 53.31	2(T60) 48.89	3(C) 41.69
3(C) 41.60	11.62 **	7.20 **	
2(T60) 48.89	4.42 *		
1(T100) 53.31			

** significant at α .01
* significant at α .05

Critical Differences:	r=2	r=3
$q_{.99}(r,24)\sqrt{MS\ within/n}$	4.91	5.63
$q_{.95}(r,24)\sqrt{MS\ within/n}$	3.62	4.38

Appendix B-V

i)

THREE WAY ANALYSIS OF VARIANCE FOR MAXIMUM

HEART RATES IN BEATS PER MINUTE

Summary Table:

Source	SS	df	MS	F	P
Between Subjects	2451.00	35			
A	35.00	2	17.50	0.23	<.80
B	291.00	3	97.00	1.29	<.31
AB	321.00	6	53.50	0.71	<.65
Subj. w. grps.	1804.00	24	75.17		
Within Subjects	657.00	36			
C	24.00	1	24.00	1.35	<.26
AC	1.00	2	0.50	0.03	<.98
BC	134.00	3	44.67	2.52	<.09
ABC	72.00	6	12.00	0.68	<.68
C x subj. w. grps.	426.00	24	17.75		

Appendix B-VI

i)

THREE WAY ANALYSIS OF VARIANCE FOR BLOOD LACTATE CONCENTRATIONS AT MAXIMAL WORK IN MILLIGRAMS PER HUNDRED MILLILITRES OF BLOOD

Summary Table:

Source	SS	df	MS	F	P
Between Subjects	34790.56	35			
A	9653.31	2	4826.66	7.45	<.01
B	7540.56	3	2513.52	3.88	<.03
AB	2046.31	6	341.05	0.53	<.79
subj. w. grps.	15550.37	24	647.93		
Within Subjects	8845.00	36			
C	2664.44	1	2664.44	17.90	<.001
AC	1072.63	2	536.31	3.60	<.05
BC	431.00	3	143.67	0.97	<.43
ABC	1104.63	6	184.10	1.24	<.33
Cx subj. w. grps.	3572.31	24	148.85		

ii)

TEST FOR SIMPLE MAIN EFFECTS FOR MAXIMUM BLOOD LACTATE CONCENTRATIONS (mg%) BETWEEN TREATMENTS AT POST TRAINING TEST

Source	df	MS	F	${}_{24}^{2}F$ crit.
Between	2	4118.78	10.34	α.01=5.61 α.05=3.40
Within	24	398.35		

Appendix B-VI

iii)

NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS FOR MAXIMUM BLOOD LACTATE CONCENTRATIONS (Mg%) AT POST TRAINING TEST

GROUP MEANS	1(T100) 103.67	2(T60) 99.00	3(C) 69.50
3(C) 69.50	34.17 **	29.50 **	
2(T60) 99.00	4.67		
1(T100) 103.67			

** Significant at α.01

Critical Differences:	r=2	r=3
$q_{.99}\ (r,24)\sqrt{\text{MS within}/n}$	22.81	26.15
$q_{.95}\ (r,24)\sqrt{\text{MS within}/n}$	16.82	20.33

Appendix B-VI

iv) Scheffe's Contrast

Groups	C_1	$T100_1$	$T60_1$	C_2	$T100_2$	$T60_2$	$\Sigma c\bar{X}$	$(\Sigma c\bar{X})^2$	$\Sigma\frac{c^2}{n}$	MS_w
Means	67.5	84.9	82.6	69.5	103.7	99				
Coefficients_1	-1	1	0	1	-1	0	16.8	282.24	$\frac{1}{3}$	398.35
Coefficients_2	-1	0	1	1	0	-1	14.4	207.36	$\frac{1}{3}$	398.35

$$S_1 = \frac{(\Sigma c\bar{X})^2}{(\Sigma\frac{c^2}{n}) \text{ MS within}} = \frac{282.24}{132.78} = 2.12$$

$$S_2 = \frac{(\Sigma c\bar{X})^2}{(\Sigma\frac{c^2}{n}) \text{ MS within}} = \frac{207.36}{132.78} = 1.56$$

$${}^{2}_{24}F \text{ crit } \propto .05 = 2.62$$

Appendix B-VII

i)

THREE WAY ANALYSIS OF VARIANCE FOR MAXIMUM OXYGEN PULSE

IN MILLILITRES OF OXYGEN PER HEART BEAT

Summary Table:

Source	SS	df	MS	F	P
Between Subjects	749.74	35			
A	44.86	2	22.43	2.74	< .09
B	418.05	3	139.35	17.05	< .001
AB	90.65	6	15.11	1.85	< .14
subj. w. grps	196.18	24	8.17		
Within Subjects	390.08	36			
C	217.23	1	217.23	70.36	< .001
AC	73.21	2	36.61	11.86	< .001
BC	16.64	3	5.55	1.80	< .18
ABC	8.91	6	1.48	0.48	< .82
C x subj. w. grps	74.09	24	3.09		

ii)

TEST FOR SIMPLE MAIN EFFECTS FOR MAXIMUM OXYGEN PULSE

(ml/heart beat) BETWEEN TREATMENTS

AT POST TRAINING TEST

Source	df	MS	F	${}^{2}_{24}F$ crit
Between	2	58.17	10.33	α .01=5.61 α .05=3.40
Within	24	5.63		

Appendix B-VII

iii)

NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS FOR

MAXIMUM OXYGEN PULSE (ml/heart beat)

AT POST TRAINING TEST

GROUP MEANS	1(T100) 22.04	2(T60) 20.54	3(C) 17.71
3(C) 17.71	4.33 **	2.83 **	
2(T60) 20.54	1.50		
1(T100) 22.04			

** significant at α.01

Critical Differences:	r=2	r=3
$q_{.99}(r,24)\sqrt{MS\ within/n}$	2.69	3.08
$q_{.95}(r,24)\sqrt{MS\ within/n}$	1.99	2.40

Appendix B-VIII

i)

THREE WAY ANALYSIS OF VARIANCE FOR VENTILATORY EQUIVALENT EXPRESSED AS VENTILATION IN LITRES PER MINUTE DIVIDED BY THE OXYGEN CONSUMPTION IN LITRES PER MINUTE

Summary Table:

Source	SS	df	MS	F	P
Between Subjects	13.45	35			
A	0.88	2	0.44	1.26	<.31
B	3.45	3	1.15	32.9	<.04
AB	0.71	6	0.12	0.34	<.91
subj. w. grps.	8.40	24	0.35		
Within Subjects	9.28	36			
C	1.08	1	1.08	3.70	<.07
AC	0.18	2	0.09	0.31	<.74
BC	0.39	3	0.13	0.45	<.73
ABC	0.63	6	0.10	0.36	<.90
Cx subj. w. grps.	7.00	24	0.29		

APPENDIX C

AVERAGE WORK LOAD PERFORMED BY EACH FITNESS LEVEL OVER THE SEVEN WEEK TRAINING PROGRAM IN KILOPOND METERS

AVERAGE WORK LOAD PERFORMED BY EACH FITNESS LEVEL

OVER THE SEVEN WEEK TRAINING PROGRAM

IN KILOPOND METERS (MEAN ± S.D.)

Fitness Levels in Increasing Order	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
Fitness Level 1	9238.5 ± 1463.7	10755.9 ± 2677.8	12655.5 ± 3013.0	13609.1 ± 1372.9	16211.1 ± 2480.0	19383.4 ± 5795.0	21796.8 ± 3220.0
2	9218.6 ± 2167.3	11500.7 ± 2750.7	12190.6 ± 2940.3	14485.9 ± 2995.6	17030.6 ± 4030.6	17517.9 ± 3196.4	21562.0 ± 2945.1
3	9510.1 ± 3663.5	11984.1 ± 2917.4	13946.3 ± 3795.7	18720.6 ± 7324.7	21356.1 ± 7839.9	23643.7 ± 6879.1	25153.2 ± 5861.0
4	9698.2 ± 2955.4	11414.4 ± 2968.6	13699.3 ± 4686.3	15701.6 ± 4795.7	18757.5 ± 8512.9	19192.5 ± 7316.7	23176.6 ± 5369.7

APPENDIX D

THE EXPERIMENTAL DESIGN

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